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ABSTRACT

The understanding of process optimisation techniques and ways of efficient data acquisition of the processes in intralogistics is a necessity for industries to survive in this competitive world. Also, proper data communication about the processes is a key factor in the success of any industry. The (Supervisory Control and Data Acquisition) SCADA system, which is utilized in the current industrial revolution, is a key player in increasing the performance of intralogistics as well as the manufacturing industry. The importance of knowing SCADA components along with international standards is necessary to build any fool-proof modern manufacturing infrastructure. Current trends and technologies being employed by leading SCADA system providers need to be put on a single platform. The research on SCADA system components is carried out, keeping in mind current SCADA system standards designed by diverse international organizations. The system specifications were also discussed, with the Siemens SCADA system. To support the theory, Honeywell Inc. product Experion was investigated. The acquired theoretical knowledge then applied to an issue present in the Institute of Logistics Engineering (ITL) where issues in data acquisition of closed loop conveyor belt carrying different weighing containers were addressed. Theoretical research was conducted to aid in the systematic resolution of the current issue at ITL. Firstly, theoretical knowledge assisted in generation of ideas to find a solution to an existing problem, and next, through the case study, a framework to address an issue was created. To address this issue, a National Instruments (NI) software solution, Laboratory Virtual Instrument Engineering Workbench (LabVIEW), was applied. It is a programming tool that can be used by non-programmers to create complex programming. The software then integrated with the conveyor and various sensors were used to collect real time data. After the implementation of the software, the data acquisition issue was effectively addressed, and now with the use of conveyor systems, real-time data acquisition is taking place. The data can now further be utilized for process improvement and also to carry out preventive maintenance of the system. The knowledge of this study can be applied to any other similar system to improve overall performance keeping within international protocols.

Keywords: SCADA, Data Acquisition, SCADA Standards, Automation Software-LabVIEW, Intralogistics

ZUSAMMENFASSUNG

Das Verständnis von Prozessoptimierungstechniken und Möglichkeiten zur effizienten Datenerfassung der Prozesse in der Intralogistik ist für die Industrie eine Notwendigkeit, um in dieser wettbewerbsorientierten Welt zu überleben. Auch die ordnungsgemäße Datenkommunikation über die Prozesse ist ein Schlüsselfaktor für den Erfolg jeder Branche. Das SCADA-System (Supervisory Control and Data Acquisition), das in der gegenwärtigen industriellen Revolution eingesetzt wird, ist ein wichtiger Akteur bei der Steigerung der Leistung der Intralogistik und der Fertigungsindustrie. Die Kenntnis der SCADA-Komponenten und der internationalen Standards ist für den Aufbau einer modernen und zuverlässigen Fertigungsinfrastruktur unerlässlich. Aktuelle Trends und Technologien, die von führenden SCADA-Systemanbietern eingesetzt werden, müssen auf einer einzigen Plattform zusammengefasst werden. Die Untersuchung der SCADA-Systemkomponenten wird unter Berücksichtigung der aktuellen SCADA-Systemstandards durchgeführt, die von verschiedenen internationalen Organisationen entwickelt wurden. Die Systemspezifikationen wurden auch mit dem Siemens SCADA-System diskutiert. Zur Unterstützung der Theorie wurde das Produkt Experion von Honeywell Inc. untersucht. Das erworbene theoretische Wissen wurde dann auf ein Problem angewandt, das im Institut für Technische Logistik (ITL) auftrat, wo Probleme bei der Datenerfassung von Förderbändern mit geschlossenem Kreislauf, die verschiedene Wiegebehälter transportieren, behandelt wurden. Die theoretische Forschung wurde durchgeführt, um bei der systematischen Lösung des aktuellen Problems im ITL zu helfen. Zunächst half das theoretische Wissen bei der Generierung von Ideen, um eine Lösung für ein bestehendes Problem zu finden, und dann wurde durch die Fallstudie ein Rahmen zur Lösung eines Problems geschaffen. Zur Lösung dieses Problems wurde eine Softwarelösung von National Instruments (NI), Laboratory Virtual Instrument Engineering Workbench (LabVIEW), eingesetzt. Dabei handelt es sich um ein Programmierwerkzeug, das auch von Nicht-Programmierern zur Erstellung komplexer Programme verwendet werden kann. Die Software wurde dann in das Förderband integriert und verschiedene Sensoren wurden zur Erfassung von Echtzeitdaten eingesetzt. Nach der Implementierung der Software wurde das Problem der Datenerfassung wirksam angegangen, und nun erfolgt die Datenerfassung durch den Einsatz von Fördersystemen in Echtzeit. Die Daten können nun zur Prozessverbesserung und auch zur vorbeugenden Wartung des Systems genutzt werden. Die Erkenntnisse dieser

Studie können auf jedes andere ähnliche System angewendet werden, um die Gesamtleistung unter Einhaltung der internationalen Protokolle zu verbessern.

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LIST OF ABBREVIATIONS

CPU	Central Processing Unit
EPA	Enhanced Performance Architecture
FBD	Function Block Diagram
HMI	Human Machine Interface
ITL	Institute of Logistics Engineering
IL	Instruction List
ISO	International Organization for Standardization
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
LD	Ladder Diagram
NI	National instruments
PLC	Programmable Logic Controller
ROM	Read-Only Memory
RTU	Remote Terminal Unit
SFC	Sequential Function Chart
SCADA	Supervisory Control and Data Acquisition

1 Introduction

1.1 Background

Today it is the era of industry 4.0 where all the industrial processes work towards becoming fully automated. Industry 4.0 is the reason because of which industries are revolutionized. The industries are using technologies such as cloud computing, Internet of Things (IoT), AI, machine learning, data analysis. So, to serve these tasks the smart factories are loaded with various advanced sensors which are then used for process data acquisition purpose. Data acquisition plays crucial role in fourth industrial revolution as it can benefit organisation with collection of data for process control, process improvement, better decision makings, etc. This collected data also interlinks the inter-departments and opens new space of transparency in data sharing within different enterprises in the organization.[1]

Supervisory Control and Data Acquisition (SCADA) system acts as a pillar of Industry 4.0. As the full form of SCADA suggests it is used in controlling and acquisition of data in the industry and the industry could be intralogistics applications, gas generation plant, water plant, automotive industry etc. SCADA system has further applications such as reacting to the alarms, remote supervision of process, changing of configuration, generation of graphs, generation of reports etc. [2]

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a software created by NI (National Instruments) which works on a working principles of SCADA system where the virtual instrumentation is used for monitoring the hardware mechanism and uses graphical language "G". Using this tool, the VI (Virtual instrumentation) can be created using drag and drop function which reflects the real hardware so finally can be used for acquisition of different sets of data.

1.2 Aim and Objective

SCADA systems are widely used in many industries, but they have yet to be fully utilized. The purpose of this thesis is to properly comprehend the SCADA system, including its standards, components and specifications. Also, to carry out research on SCADA solution provided by one of the vendors available in the market. Additionally, to research on SCADA solution offered by National instruments (NI) named as LabVIEW programming for data acquisition.

In the end, to help understanding of the thesis's theoretical investigation of LabVIEW carry out real LabVIEW programming for the hardware setup present at Institute of Logistics Engineering (ITL).

1.3 Deliverables/ Structure of the Thesis

The thesis work considers SCADA system components, specifications, and SCADA standards for explanation. Theory of SCADA is supported by one detailed SCADA solution from one of the vendors available in the market. In the second half of the thesis, an introduction to the data acquisition tool LabVIEW is presented on the basis of data types in software and data filtering elements. Furthermore, the hardware on which experimental work got carried out is briefly discussed. In the experimental work, one example a conveyor system at Graz University of Technology's ITL is considered. This conveyor system was integrated with LabVIEW programming. As a result, in order to ensure the conveyor's flawless operation, a completely new application-based programming is created to handle data acquisition and system monitoring. In the result section, virtual user interface carrying different charts acquired after LabVIEW programming are discussed.

2 Introduction and Discussion SCADA

2.1 Fundamental Overview of SCADA

Supervisory control was initially used in electric utility networks to run remote substation equipment with the absence of staff. The Magnetic Stepping Switch created by telephone companies in the 1930s was used to multiplex one pair of lines. For security purpose, a select-check-operate approach was established, where the operator waited for device acknowledgement before operating it. Westinghouse and North Electric Company developed Visicode supervisory control on the telephone relay networks' coding techniques. [3] General Electric and Control Corporation also created their own autonomous supervision and control programme. These were utilized in airports runway landing lights, in pipelines and gas companies etc. From 1950 through 1965, these systems gained popularity. Minicomputers with 8 and 16 bits provided the first push. Several years later, microprocessors represented the second technological advancement. Previously, field data collecting devices were programmed and communicated with using hard-wired equipment. However, computers allowed for greater programming and communication flexibility and here it was beginning of Supervisory Control and Data Acquisition (SCADA). Since then, several organizations, such as the IEEE, American National Standards Institute, Electric Power Research Institute, and DNP3 Users group, among others, have taken part in the standardization of SCADA systems.[3], [4]

SCADA System perform 4 Functions such as:

1. Data Acquisition
2. Networked Data Communication
3. Data Presentation
4. Control[5]

Above stated functions are performed by Sensors, Remote Terminal Unit (RTUs), SCADA Master Unit, Programming, The Communications Network in SCADA system so it is a combination of hardware and software elements.[5], [6] SCADA is a control system architecture consisting of computers, networked data transfers, and graphical user interfaces for high-level monitoring of equipment and processes. In addition, it encompasses sensors and other devices, such as programmable logic controllers, that interface with process plant or machinery.[7][8], [9]

2.2 SCADA System Components

SCADA consists of 4 major system elements.

2.2.1 Human Machine Interface (HMI)

Big SCADA systems have many servers and distributed software applications. Therefore, in these systems, many servers are set to continually regulate and monitor system activities in order to maintain system integrity in the event of a breakdown and here comes HMI in action.[10], [11] HMI/SCADA is a type of software-based control system architecture that employs networked data to offer operators with a graphical user interface for monitoring the operation of several equipment's and issuing process orders and settings. This may be done from a dedicated screen, mobile device, or any PC with a web browser linked to the control network. HMI/SCADA enables operators to enhance situational awareness, the mobility of viewing at any time and place, and the management of critical equipment, therefore providing a consolidated view of operations.[12] In small-scale operations, the operator is permitted to configure the controllers' set points and algorithms. The device displays status information and prior reports graphically to the operator or authorized users during large-scale activities.[10], [11] With the rising usage of personal computers, office computer networking has become ubiquitous, and SCADA systems that can network with office-based personal computers are now available. In fact, many modern SCADA systems can operate on similar computer servers and PCs as those used for typical office applications. [13] In modern SCADA system it serves as the storehouse for reported data acquired in real-time or near real-time from distant terminal devices connected to it.[3]

HMI/SCADA gathers information from Remote Terminal Units (RTUs), PLCs (Programmable Logic Controls), and other control devices such as flow meters and temperature controllers. These data are displayed to the operator using an HMI. The HMI enables the operator to view what is happening in the plant in real time, including customized simulated displays, alerts, trends, etc., in order to make choices on any machine controls or settings adjustments. HMI/SCADA can also be linked to other technologies, such as a data historian, to enable historical trends and other forms of analysis. In reality, the foundation consists of acquiring industrial data, merging it with other useful data sources for context, and maintaining a historical record. The cornerstone for meaningful results is data that has been converted into information.[12]

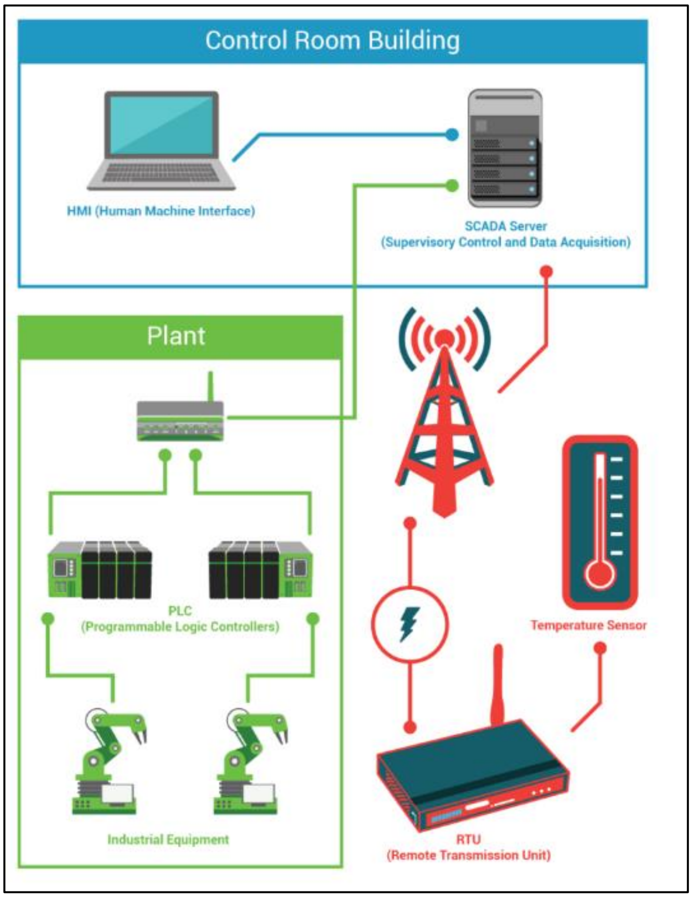


Figure 1:SCADA System[14]

2.2.2 Remote Terminal Unit (RTU) or Programmable Logic Controller (PLC)

2.2.2.1 Remote Terminal Unit

An RTU is a transducer or sensor that interfaces the electrical circuitry with the process instrumentation and control equipment as can be seen in Figure 1. Physical parameters like in the used case force, torque, velocity, etc. are measured by detecting a change in the electrical property of a transducer component that is indicative of the physical change. A single RTU can measure several sorts of parameters. The Input/Output circuitry of an RTU might be analog or digital, depending on the results of the measurements. Analog measures correspond to a numeric range of continuous values that are transformed using an ADC, such as a temperature scale, whereas digital measurements contain a restricted number of states (often two) that are mostly used for flagging. To regulate process equipment, certain signals can be produced. RTUs are microprocessor-based devices that do these conversions mostly internally. [3] When linked to sensors and monitors at the remote site, the RTU enables data transfer to the central station, where data collection and monitoring are done. RTU and central stations often communicate over serial ports (such as RS232).[11], [12]

2.2.2.2 Programmable Logic Controller

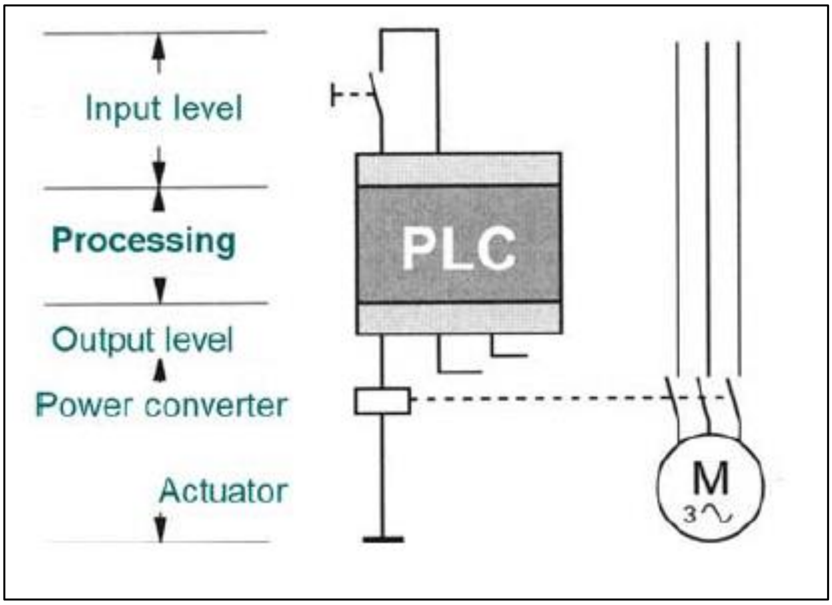


Figure 2: A programmable Logic Controller[15]

The monitoring of sensors task is also carried out by a programmable logic controller. In this approach, a PLC stands for data collection, obtaining crucial information on the system's flow and input. To do this, the PLC will also execute simple interventions, triggering outputs when the system's predefined parameters are satisfied. A PLC is a flexible piece of equipment that can withstand tough circumstances and offers extensive programming and real-time use possibilities. Specifically, PLCs are responsible for controlling some of the most complicated operations in industrial plants. Frequently, they are utilized to monitor running equipment and motors. To give extra functionality, PLCs are simple to programme. Furthermore, these gadgets are expandable. This implies that they can accommodate a broad variety of operational needs.

Figure 4 gives depiction of the PLC system. The PLC was created as an improvement over relays and timers, which were once prevalent in industrial machinery. The monitoring capabilities of modern PLCs are far more complex and the data they deliver is becoming more dynamic. [16], [17] It will be safe to say that PLC and RTU perform the same task. Fundamental

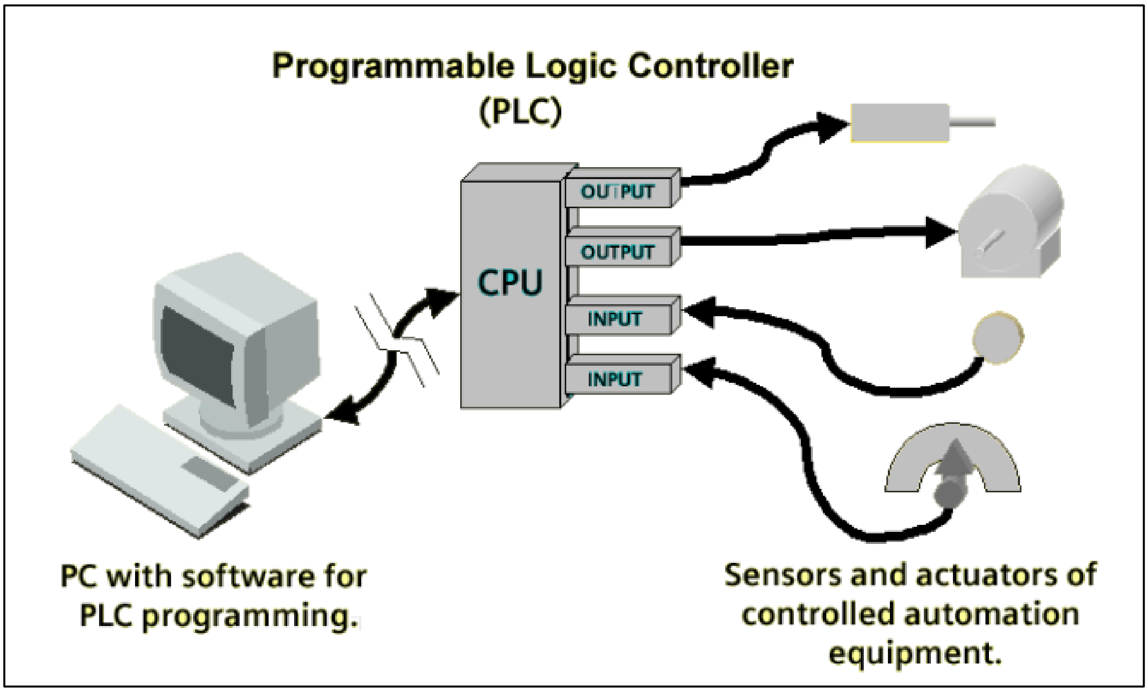


Figure 3: PLC Connections[18]

difference in between these two is both of them operate at different place that means RTU can be operated from remote sites and is connected to rest of the system with wireless networking. In contrast PLC communicates with all the sensors and rest of the system with wired network format.

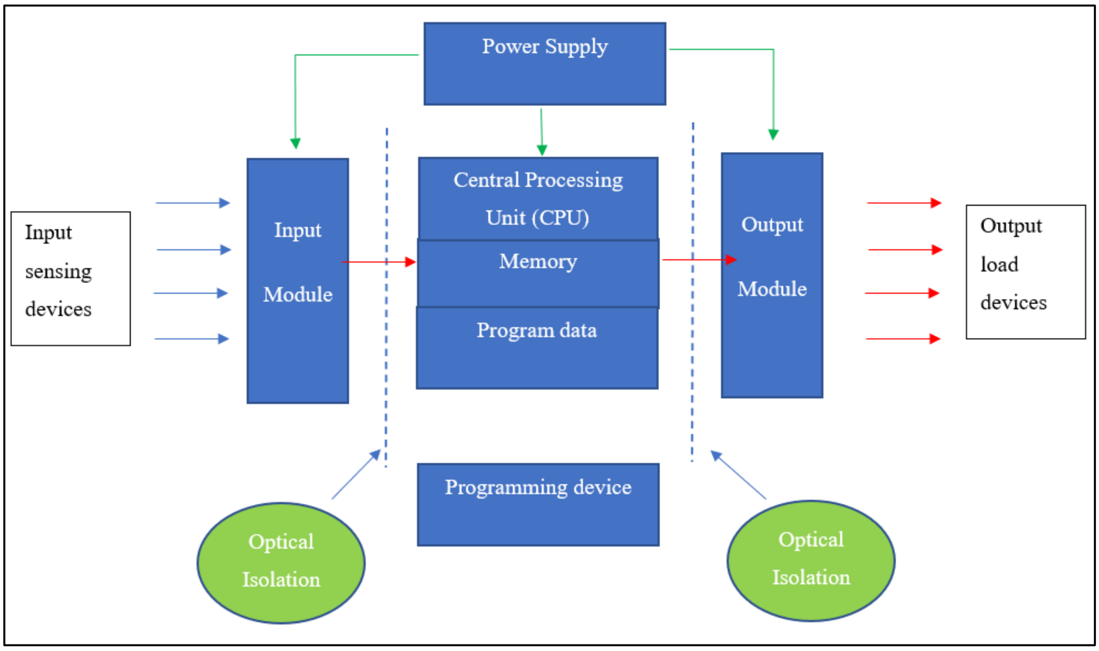


Figure 4: PLC SYSTEM [19]

A Central Processing Unit (CPU) acts as the PLC's brain. It consists of a memory chip and integrated circuits for control logic, monitoring, and communication. The CPU guides the PLC to carry out control commands, connect with other devices, perform logical and mathematical operations, and conduct internal diagnostics. The CPU executes memory procedures, continuously examining the PLC (PLC controller is redundant) to prevent programming mistakes and guarantee the integrity of the memory.[20]

Inputs, outputs, a power supply, as well as external programming devices are operated by PLCs. Memory supplies the operating system with persistent storage for CPU-used data. RAM holds status information for input and output devices, as well as values for timers, counters, and internal devices.[21] The read-only memory (ROM) of the system saves data permanently for the operating system. To upload data into the CPU of a PLC, a programming device, such as a computer or console, is required. A CPU operation cycle consists of the subsequent steps: a) initiate scan; b) conduct internal checks; c) analyse inputs; d) execute programme logic; and e) update outputs. The programme iterates with updated results. [20], [22]

2.2.3 PLC Programming

PLCs are industrial process control computers that have been "ruggedized" and tailored to control the production process. By using this technology, nearly all industrial processes have been upgraded and automated to keep ahead of the competition. Programming in the HMI or master station is used to generate diagrams and maps that give crucial data in the case to send alerts about a process or it notifies event failure also it has been used to control the process. Programming interfaces for the majority of commercial SCADA systems are standardized. [23] According to International Electrotechnical Commission (IEC)61131-3 standards keeping in mind there are various ways to perform programming. IEC 61131-3 is explained further. The programming methods are being utilized are explained one by one.

2.2.3.1 PLC Programming Methods

- **Structured Text (ST)**

Structured Text is a programming language which is text-based, and it is used to build PLC logic, comparable to Python, Visual Basic, and C. It utilizes less CPU memory and is useful for moving large amounts of data and doing extensive mathematical calculations. Complex PLC logic is simpler to program and comprehend.[23], [24]

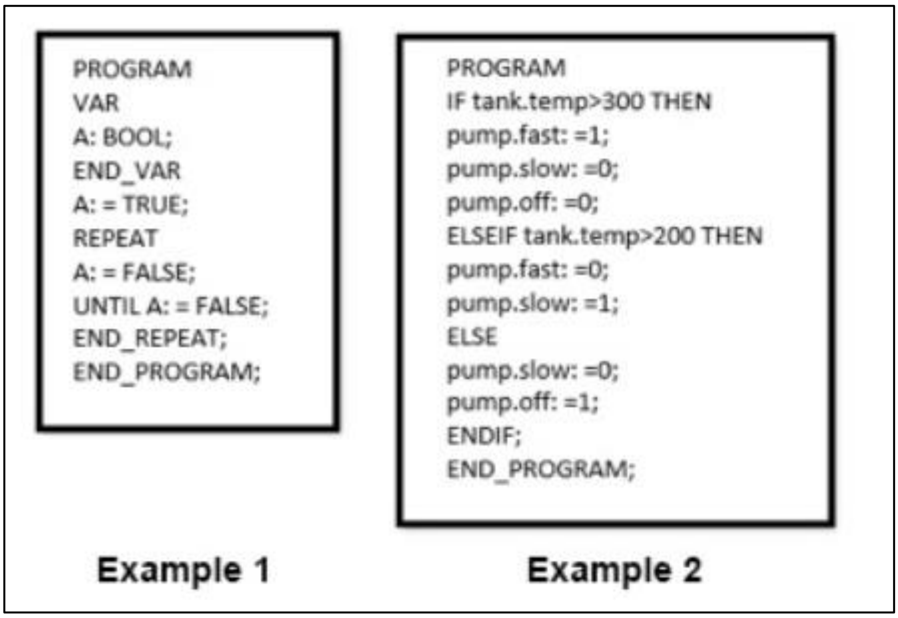


Figure 5: Examples of Structural texts[23]

Structured Text syntax is designed to resemble that of a high-level programming language, complete with loops, variables, different conditions, as well as operators.[25] As can be seen in Figure 5 the text includes different symbols, colons, semicolons etc. They are used to give meaning to the text. Out of them some are variables, some are operators, some can be functions. Depending on type of the data needs to be stored there is a variety available in data types. The data types are divided into two categories such as Elementary data types and Derived data types The detailed description of data types is explained further. [25] Elementary data types are listed below.

- Boolean data type
- String data type
- Integer data type
- Time data type
- Floating points data type

And derived data types are:

- Structured data types
- Enumerated data types
- Sub-range data types
- Array data types

The derived data types are custom data types. They are made with constructing key words TYPE and END_TYPE. Different data types contain different data formats and therefore different values. [25]

- **Ladder Diagram (LD)**

Ladder logic is a programming language for programming PLCs. Ladder logic is one graphical PLC programming language that defines logic operations by using ladder diagrams, symbolic notation, much like a conventional relay logic circuit. Using ladder logic, quick and simple machine tasks and sequences can be created. The applications of usage of Ladder Diagram is in Intralogistics including material handling conveyor system, Logistic package conveying and sorting, cement batching etc. Before introduction of ladder logic, the automation used to get carried out by relay logic with the use of hard-wired control system. [26]

The parts of Ladder diagram are shown in Figure 6. Ladder diagrams are created using rails and rungs. If the rail is used it defines the start and end part of each code line. And the rungs are used to connect all components together. Inputs are actually connected to the PLC terminals and with wires used to control the action, it could be limit switch or push buttons. Output devices that are being turned ON or switched OFF and that be electric motors or valves. Logic expressions are used together with input and output for formulation of desired control operation. The descriptions that are assigned to the addresses are referred to as the tag names. Address notation specifies PLC input, output, as well as logic expression memory address. In the end comments are used in the beginning of each rung and that depicts the control operation that is being carried out in the rung.[26]

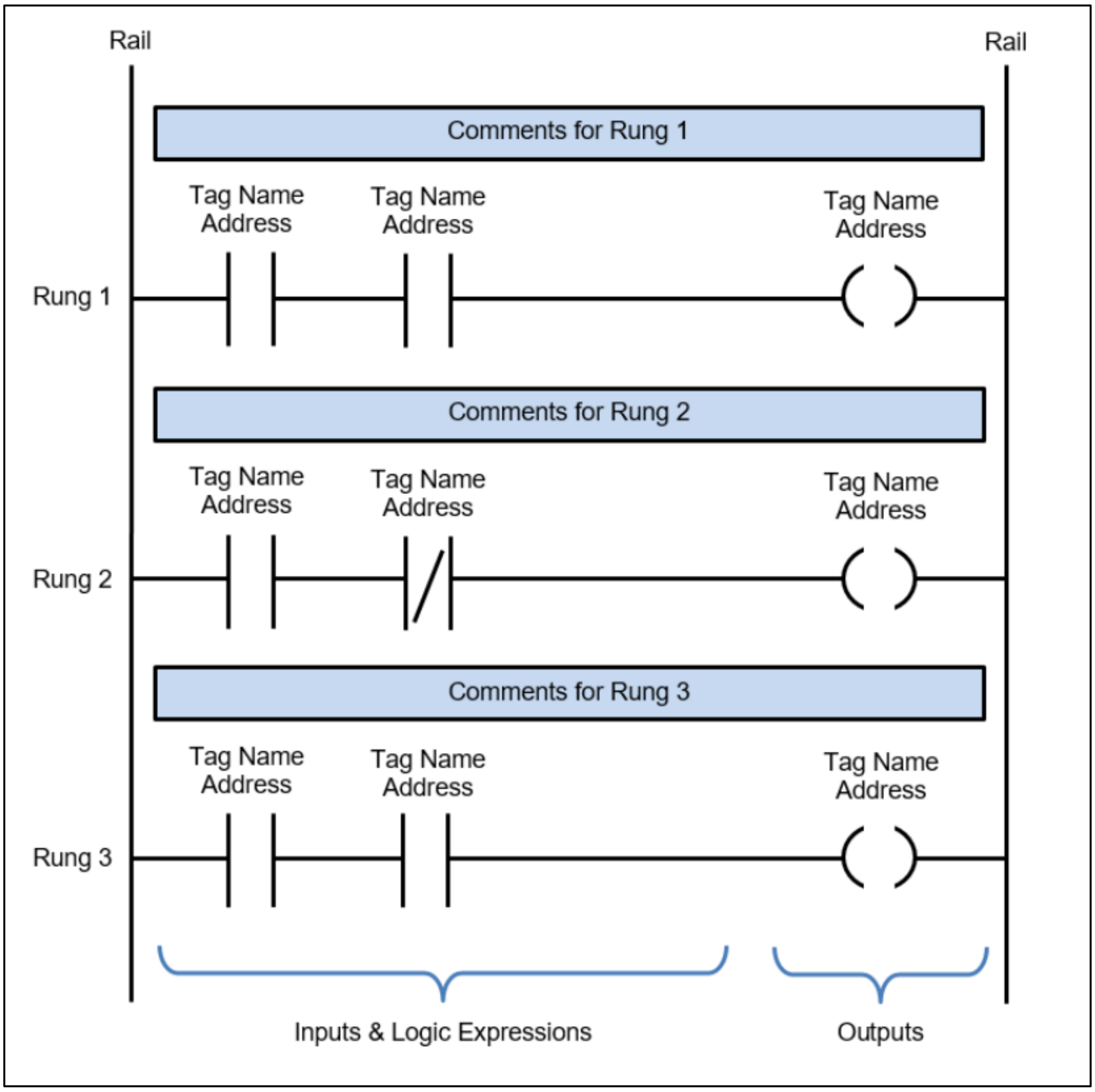


Figure 6: Parts of Ladder Logic Diagram[26]

- **Function Block Diagram (FBD)**

The Function Block Diagram programming language is graphical in representation. It functions using a list of networks. Each network consists of a graphical representation of logical or arithmetic expressions, the execution of a function block or return of instruction.[27]

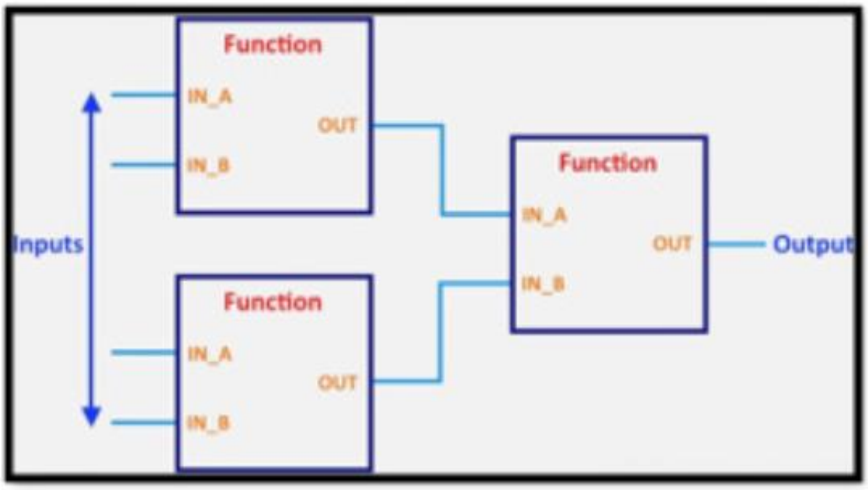


Figure 7: Function Block Concept[23]

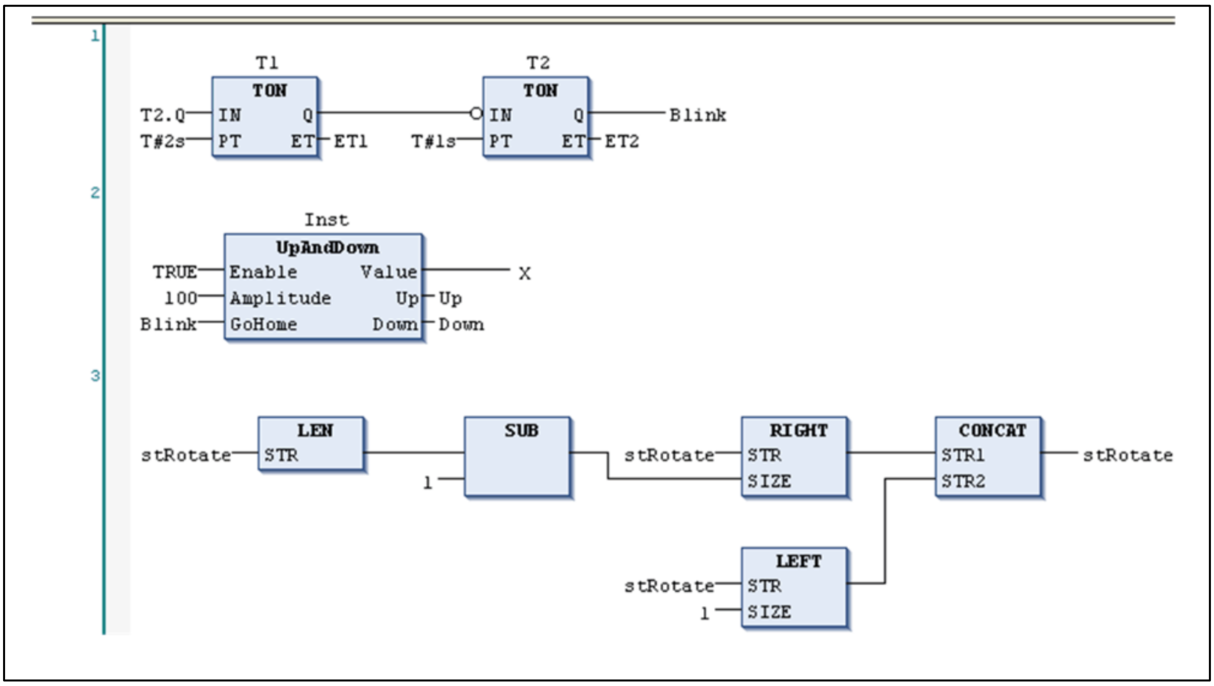


Figure 8: Sample Function Block Diagram[27]

Every Function is in advance pre-programmed to perform some specific tasks and those function are then connected with input and output by user.[23] Functions and function block are two different concepts. Functions contain trigonometric functions such as sin, cos then arithmetic functions like addition and subtraction whereas function block includes counters, timers, PID etc. FBD is a program combining functions with functional blocks in one block and this block then becomes input to the next. An FBD can be employed to describe the behaviour of both function blocks and programs. It can also be used to describe actions and transitions in sequential function charts (SFCs). [23], [28]

- **Sequential Function Chart (SFC)**

SFC is another language which is identified by IEC 61131-3 and is a standard for PLC with the use of ladder diagram. In contrary to other text-based programming languages, SFC is a visual programming language. With SFC large and complex processes can be broken down into small parts. The multiple states of operations can be easily represented using SFC as it has been broken down into pieces. [29]

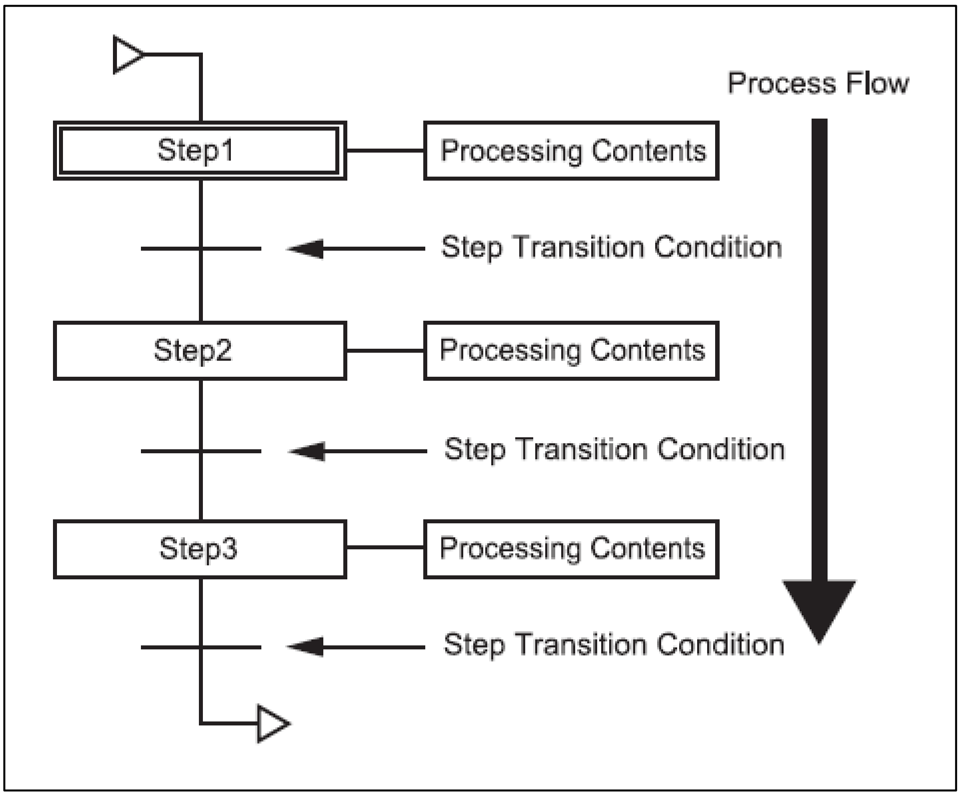


Figure 9: SFC working principle[30]

The first box denotes the beginning of the process being carried out. A horizontal line runs between two states to connect them. The transitional conditions are represented by the horizontal lines that run between the boxes. There are occasions when transition conditions can be represented by a much smaller rectangle that is situated in between the larger phases. After one stage of the process has been finished, the process will only advance to the next state if the transition condition(s) have also been fulfilled. Every one of the states also has outputs that correlate to it. The outputs are depicted as square or rectangular boxes that are horizontally connected to their corresponding states.[24], [29] Every SFC must satisfy two conditions:

- Between two steps there should be transition condition.
- Two transition conditions must be separated by a step.

The program flow is possible in two ways out of one is branching in Parallel and branching in Selective way.

- Parallel Branches in Programming

  In parallel branching, it is allowed to branch two or more states in parallel order only if a single transition condition is satisfied.[29]

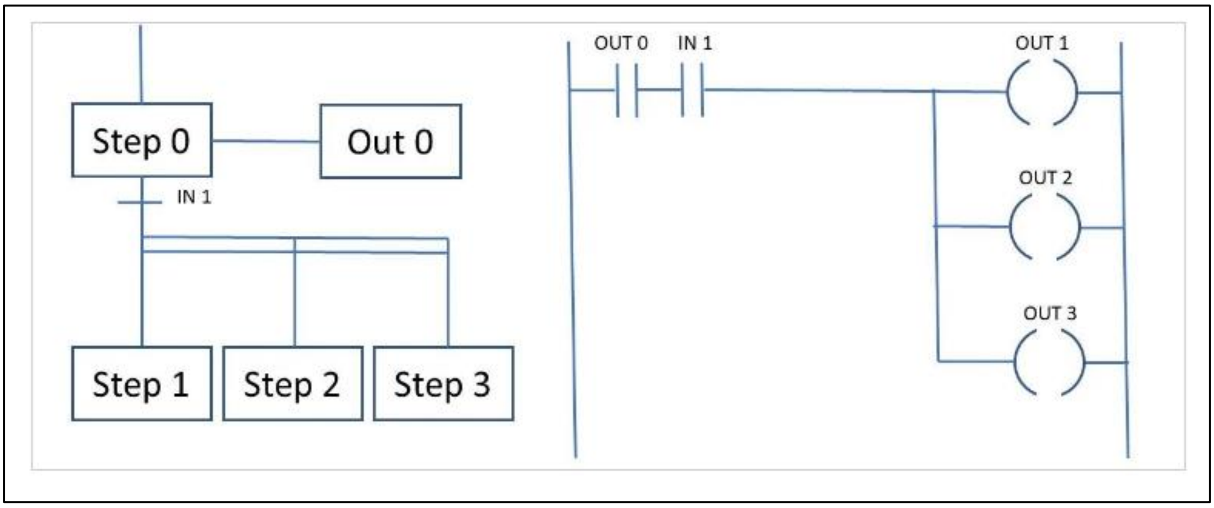


Figure 10: Parallel Branching in SFC[29]

- Selective Branches in Programming

  In contrast to parallel branching, not all of the subsequent phases begin at the same time in Selective Branches. There is a transition condition that must be satisfied prior to moving on to the next step in the branch. It is necessary for OUT 0 and IN 1 to take place before step 1 can begin. It is necessary for OUT 0 and IN 2 to take place before step 2 can begin.

Each succeeding step has its own unique set of transition conditions, which are not reliant on one another. [24], [29]

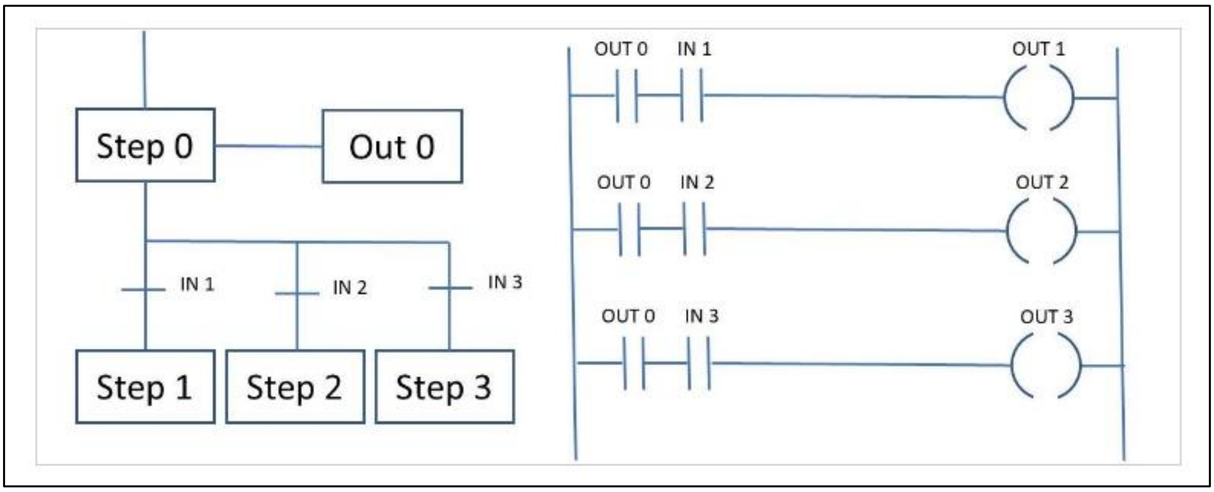


Figure 11: Selective Branches in SFC[29]

- The advantages of using SFC programming has many advantages-
  - Individual piece of logic can be repeated quickly.
  - Troubleshooting is faster and easier
  - Time to design and debugging program is less
  - Updating and enhancement is easy[31]

This PLC programming technique is used at a very high structured level. SFC is extremely beneficial for breaking down a large, difficult programming tasks into smaller, more manageable functions.[32]

- **Instruction List (IL)**

```
LD                  BVar1
ST                  tonInst1.IN
CAL                 tonInst1(
               PT:=t1,
               ET=>tOut2)
LD                  toninst1.Q
JMPC               mark1
ST                  tonInst2.IN

________________________________

mark1:
LD                  iVar2
ADD                 230
```

Figure 12: Instruction List Sample

Instruction List is a low-level and text-based language that makes use of mnemonic instructions; alternatively, its instructions are similar to those found in assembly language programming. Each instruction begins on a new line and contains an operator such as Jump (JMP), Call Function Block (CAL), Return (RET), as well as mathematical operators such as Add (ADD), Subtract (SUB), Multiply (MUL), and Divide (DIV), among other things. When compared to several alternative techniques for programming a PLC, this language has a low overhead and could be executed at a faster rate. This approach is prone to run-time errors, and it has the potential to result in illegal arithmetic operations or loops that never end.[23]

2.2.3.2 Data Types in Programming Language

A programming language is developed to assist programmers in processing particular types of data and producing beneficial results. Data processing is achieved by executing a series of commands known as a program. Typically, a program has many data types (such as integer, float, character, etc.) and must store the values utilized in the program. A programmer must select the appropriate data type based on his needs.[33]

Programming language LabVIEW works with numerous data types and more programming structures, and more data types are added with updates. It has been considered because this particular method is used for practical purpose. On the front panel of a virtual instrument, and what are the types of data represented by several forms of buttons and indicators (VI) is presented.

- **String Data Type**

A string consists of both displayable and non-displayable American Standard Code for Information Interchange (ASCII) characters. Strings are platform independent. LabVIEW variant of string data type is shown in Figure 13. Among other applications, they are utilized in the following:

- Simple text message generation
- Sending commands to measurement devices in order to control them. The device's feedback may be in the form of ASCII or binary strings that may be translated to numeric values.
- Storing numerical values on a data medium. To save numeric values on disk within an ASCII file, one must first transform the numbers to strings.
- Developing instructions and prompts-containing dialog boxes
- Tables, text entry fields, and labels on the front panel all utilize strings. For instance, one may format or parse strings using the VIs and built-in functions of LabVIEW. LabVIEW displays strings in the colour pink.

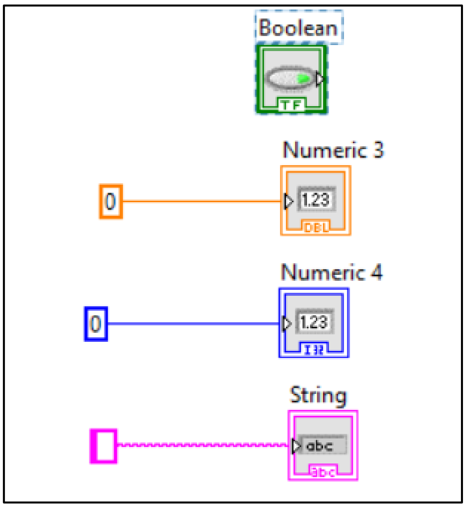


Figure 13: Data types

- **Numerical Data type**

Programming language can represent numeric data as complex, floating point, fixed point, integer, and unsigned integer numbers. In Figure 13 it is shown. Language displays complex numeric, double-precision, and single-precision numbers in orange. Blue is used to denote whole numbers.

- **Boolean Data Type**

In LabVIEW, Boolean values are represented by eight bits. Boolean can be seen in Figure 13. LabVIEW uses Boolean values to represent 0 and 1, or TRUE and FALSE. The Boolean value is FALSE if the 8-bit value is 0. All numbers greater than 0 indicate TRUE. For example, Boolean values represent digital data. Another application is for front panel controls, such as switches, to manage execution hierarchies (e.g., Case structure). Typically, a Boolean element is a conditional statement for leaving while loops. In LabVIEW, Boolean values are green.

- **Dynamic Data Type**

The majority of Express VIs employ the dynamic data type, denoted by a dark blue terminal. Using the function Convert to Dynamic Data VI and Convert from Dynamic Data VI to convert floating-point and boolean values to dynamic data of the following data types:

- 1D array containing waveforms
- 1D array of Scalars
- 1D scalar array - current value
- 1D array of scalars with a single channel.
- 2D array of scalars in which the columns are channels.
- 2D array of scalars where rows are channels.
- single scalar
- single waveform

The dynamic data type is created exclusively for use with Express VIs, hence it is incompatible with the majority of other LabVIEW functions. In order for a LabVIEW VI or function to analyze or otherwise handle dynamic data, the data must be changed beforehand. [34]

- **Arrays, Clusters and Enum**

An array is represented as a box on the panel having an element data type display and an index display. On a graph display, an array of numbers or points can be shown in two dimensions.[35] Related data is grouped together using array and clusters. Data of the same data type are grouped together in arrays, whereas data of various data kinds are grouped together in clusters. Arrays could hold numeric values, boolean values, paths, strings, waveforms, and clusters. They are particularly handy for repeating calculations or comparable data. Arrays are not limited to storing waveforms; they may also hold the output values of loops. In this scenario, each iteration of the loop creates a new array element. [34] Clusters permit the grouping of diverse data kinds. The LabVIEW Errors cluster is an example of a cluster since it comprises a boolean value, a numeric value, and a string. In command-oriented programming languages, a cluster equates to a record or structure. By grouping several data items into a cluster, the block diagram is simplified and subVIs require fewer connector pane connections.

Enumeration is a collection of data kinds. Enum controls, constants, and indicators are available. Every Enum includes a string and a number. So Enum elements display enumerations. Enum components are advantageous because numbers are easier to manage than strings on a block diagram.

2.2.3.3 Condition of Acquired Signal

Rather than amplifying or altering the waveform of the AC signal, signal conditioning consists of a frequency selection process. Numerous analog transmissions are composed of signals with varying frequency. Signals of varying frequencies are combined to produce a signal that is either the addition of the two frequencies or the difference of the two frequencies. Each of these signals can be independently processed to transmit the information contained in the original signals. Therefore, it is necessary to separate the intended signal by its frequency from other signals with various frequencies. This requires frequency selection signal conditioning. [36] Signal filtering is one of the ways to condition signals and extract and then process necessary part of the signal. Concept of filtering is being used in the designed VI to remove unnecessary disturbance from the signal.

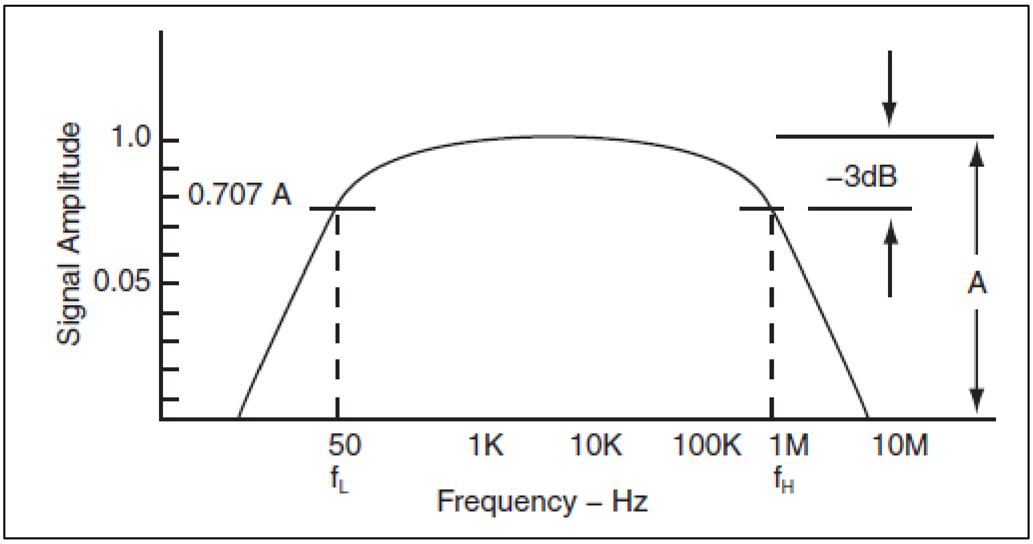


Figure 14: Band Pass Filter[36]

- **Band Pass Filter**

The mid-band gain of the curve is A, and this gain is maintained up to the high-frequency cut-off frequency f_H and bottom to the low-frequency cut-off frequency fL. The gain is lowered to 0.707%A at f_H and f_L. Since the gain at the cut-off points is –3 dB below the midband gain, these spots are referred to as the "minus 3 dB" points. As the curve depicts, a signal with a frequency significantly higher than f_H will be attenuated, that is, it will have a much-reduced amplitude; the higher the frequency, the greater the attenuation. Also, signal frequencies below f_L will experience amplitude attenuation, the lower the frequency, the greater the attenuation. All frequencies between f_L and f_H will have a constant gain and will not be attenuated. This type of frequency response curve is representative of a band-pass filter. It transmits signals with frequencies between f_L and f_H and attenuates those with other frequencies. It can be thought of as a circuit that chooses signals with frequencies within the band and rejects those outside the band.[36]

- **Low Pass Filter**

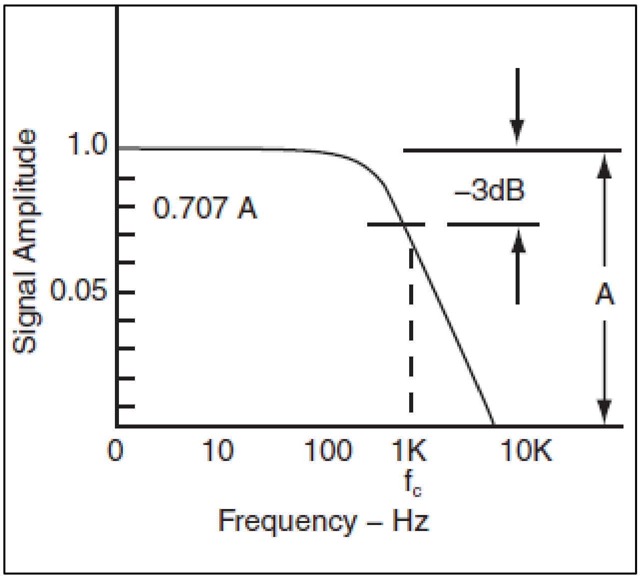


Figure 15: Low Pass Filter[36]

As the frequency of the signal is increased from zero, a frequency f_c, the cutoff frequency, is reached where the signal begins to be attenuated; subsequent frequency increases increase the attenuation. Circuits with this frequency response are referred to be low-pass filters. Signals with frequencies before f_c are not attenuated, whereas those with frequencies over f_c are. Low Pass Filters are applied during the creation of the current VI since they are the most widely utilized filter for reducing noise from the signals. Noise can be created by signals trying to couple from one circuit to another via capacitance or mutual inductance between two sets of conductors.[37] The primary distinction between high pass and low pass filters is that the high pass filter circuit allows signals with a frequency above the cut off frequency to pass, whereas the low pass filter circuit allows signals with a frequency below the cut off frequency to pass. In circuit design, the high pass and low pass filters differ; the high pass filter consists of a capacitor followed by parallel resistance. In contrast, the low pass filter circuit comprises of a resistor and a capacitor. [36], [38]. Types of low pass filter are further briefly explained as one of the many types of low pass filter is applied to few signals in the VI.

- **Low Pass Filter Classes**

The ideal low pass filter would pass all frequencies with a uniform gain in the pass area from DC to the cut-off frequency $\boldsymbol{f_c}$. Above $\boldsymbol{f_c}$, all frequencies are attenuated with an infinite attenuation rate. The different approximations of the ideal filter response include Butterworth, Chebyshev, and Bessel, as well as others.

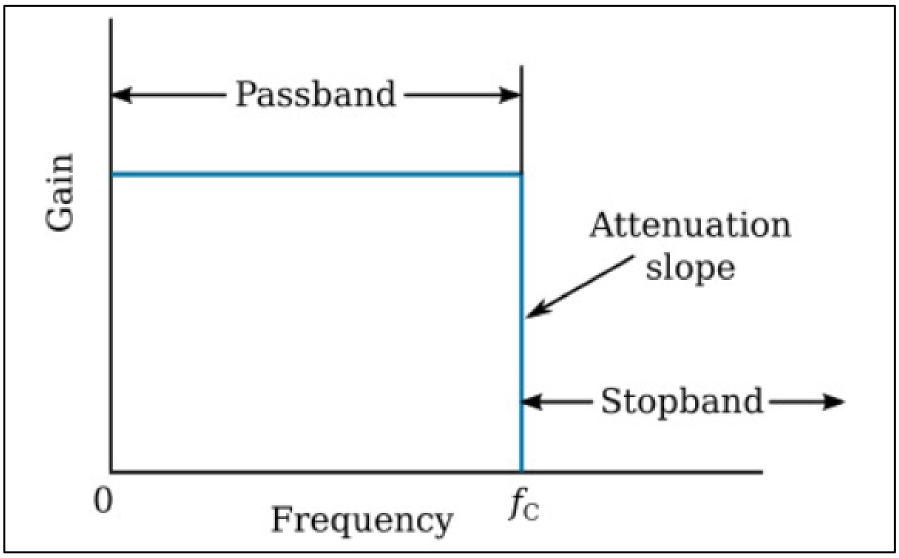


Figure 16: Ideal Low pass Filter[39]

- **Butterworth Filter**

Butterworth filter is the filter which is frequently used, and it is monotonic. Characteristic amplitude response for the Butterworth filter is depicted below. Butterworth filters has a passband response that is mostly flat, i.e. passband flatness is highlighted ideal filter quality, but it is obtained at the cost of phase linearity and attenuation slope steepness. But the Butterworth filter has a good attenuation slope, and for applications where phase linearity is not crucial, the Butterworth response is a good approximation of the ideal filter.[39] Butterworth filter is considered as active filter as it exists components like resistor, capacitor and operational amplifiers. The Butterworth filter is applied to the signals present in the experiment as it has flattest passband response amongst rest of low pass filters.

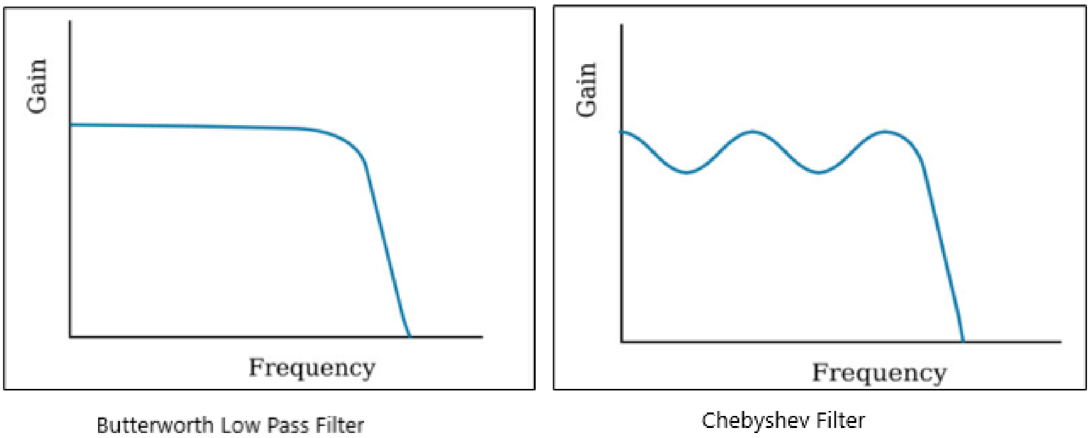


Figure 17: Butterworth and Chebyshev low-pass filter[39]

- **Chebyshev Filter**

As shown in figure below if steepness of attenuation slope, particularly in the region of cut-off, when more significant than passband flatness, this is how Chebyshev responses. The filter can be regularly applicable nonetheless, there is a ripple in the passband. Chebyshev filters design provides variety of ripple, but the amplitude in the passband remains constant for any given amount.[39]

- **Inverse Chebyshev Filter**

Both the Butterworth as well as the Chebyshev low-pass filters can only accomplish infinite attenuation at infinite frequency. However, regardless of the frequency, there will always be some signals that pass through, even those in the stopband. There is no ripple in the passband, but there is ripple in the stopband, and there is infinite attenuation at certain frequencies in the stopband if the Inverse Chebyshev is applied; there isn't oscillation in the passband, but there is oscillation in the stopband, and that there is infinite attenuation at such frequencies.[39]

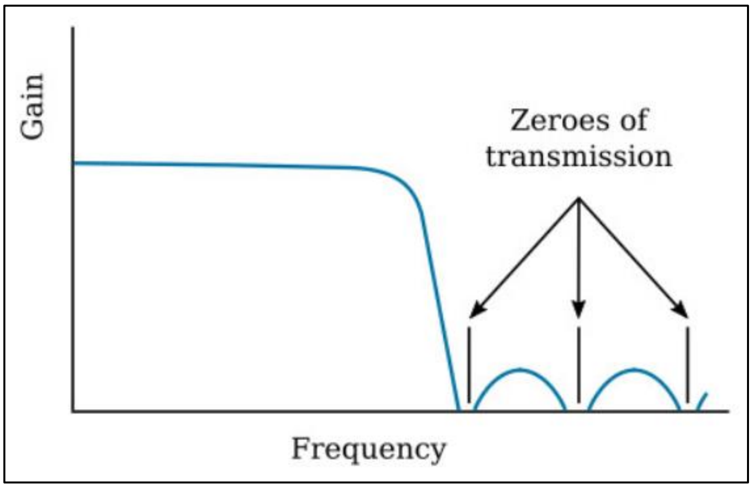


Figure 18: Inverse Chebyshev filter[39]

- **Bessel Low Pass Filter**

"The Bessel filter is the best approximation to the ideal of perfect flatness or constancy of group delay in a passband" since it has a maximally flat group-delay response. However, this only applies to low-pass filters because high-pass and bandpass Bessel filters do not have linear-phase. Figure below shows Bessel and Butterworth amplitude responses. Bessel is a poor approximation of the ideal in passband flatness and attenuation steepness. Bessel filter occasionally termed as Thomson filter that named after the founder of design method and it is as well monotonic type of filter.[39]

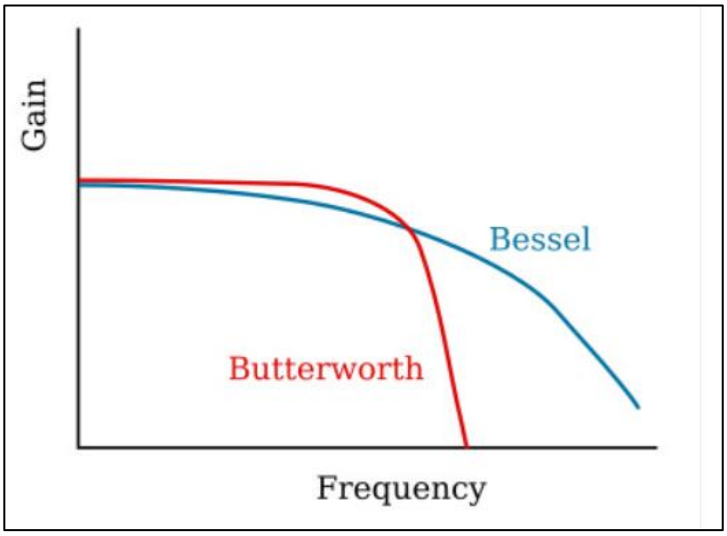


Figure 19: Comparison of Bessel and Butterworth filter[39]

- **Order in Signal Filter**

Order determines the rate at which a filter responds within the transition band. The rolloff rate of a filter rises as its order increases. The order of a filter is expressed as an integer and is obtained from the transfer function of the filter. All else being equal, a third-order filter will roll off three times as quickly as a second-order filter and three times as quickly as a first-order filter. Additionally, number of reactive components necessary for filter are determined by order of filter. A second-order filter, for instance, requires at least two reactive components: one capacitor and one inductor or two capacitors in the case of an active filter. The second order filter is being applied in the created VI as there could exist a capacitor and an inductor in the setup. As the order of filters is higher there the filter offers excellent attenuation. But two to six is the most frequently used order[40]

2.2.4 SCADA Communication

The transmission of data from an RTU to a master computer and commands from a host to an RTU must occur via a communication system. In addition, as a SCADA system may not be restricted to a single facility, the vastness of the network must be taken into account, along with speed, accuracy, security, and performance, among other crucial factors. Prior to the introduction of computer networking technologies, the majority of communication systems relied on voice communication. Likewise, SCADA communication systems were constructed with the same infrastructure and bandwidth constraints. SCADA systems have also adopted (Local Area Network) LANs and (Wide Area Network) WANs for smooth integration with standard office computer networks as a result of the business desire to include the SCADA information network into their core networks for security reasons. This has the benefit for business users of eliminating the requirement for a separate parallel network for SCADA systems.[3]

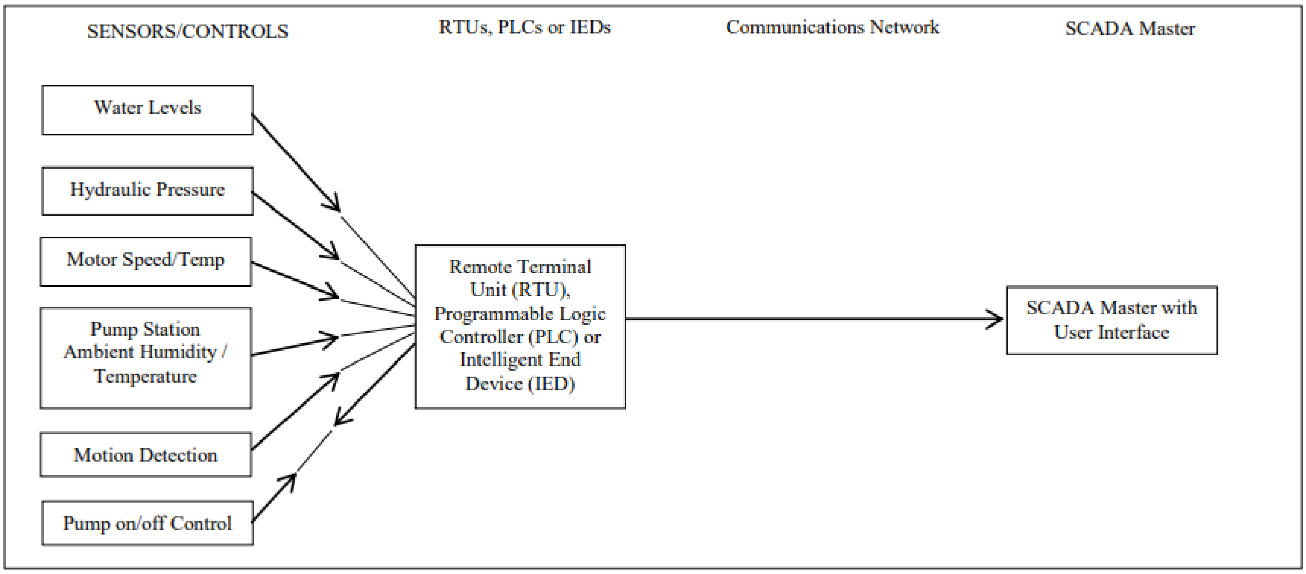


Figure 20: Ideal SCADA System[41]

Figure 20 shows simplified representation of ideal SCADA system. Here it can be seen that the data from ground level sensors, controls is sent as an input to RTU or PLC and using communication channels it has been further sent to HMI and SCADA master computer. To serve in SCADA system communication network uses numerous options.[41] The communication is carried out based on different international protocols. Big part while designing any complex SCADA system involves conforming communication protocols with connecting devices. The protocols are IEC 60870-5, DNP3 Protocol, Siemens Sinaut protocol etc. There are such 200 application protocols present. [42] If the Siemens SIMATIC manual for communication is followed then according to that there are 8 networks exist. Every single one is mentioned one to one below in a brief introduction.

➢ AS Interface

It is called as Actuator Sensor Interface (AS-i). It is international standard and is open standard for fieldbus communication between actuators and sensors which are situated on lower level. It does comply with IEC 61158 and also EN 50295 standard. AS-I is specifically considered in the interconnection between binary sensors and actuator. With the use of AS-i point to point cabling carried out for sensors and actuators can be replaced by a bus line. [43]

Basic Principle- The cable for an AS-i subnet transmits data and supplies auxiliary power to sensors and actuators. A AS-i subnets employ an electrical bus is employed by AS-i subnet. AS-i does not support wireless or optical networks.

The AS-i master polls the AS-i slave devices cyclically to ensure a predefined response time. Each slaves are assigned a unique address by a specific address programming device.

ASIsafe allows the usage of fail-safe devices on an AS-i subnet for fail-safe applications. AS International Association-certified items are AS-i. On an AS-i network, tests confirm that devices from different manufacturers may communicate with one another. Current ASInterface specifications are Specification 3.0.[43]

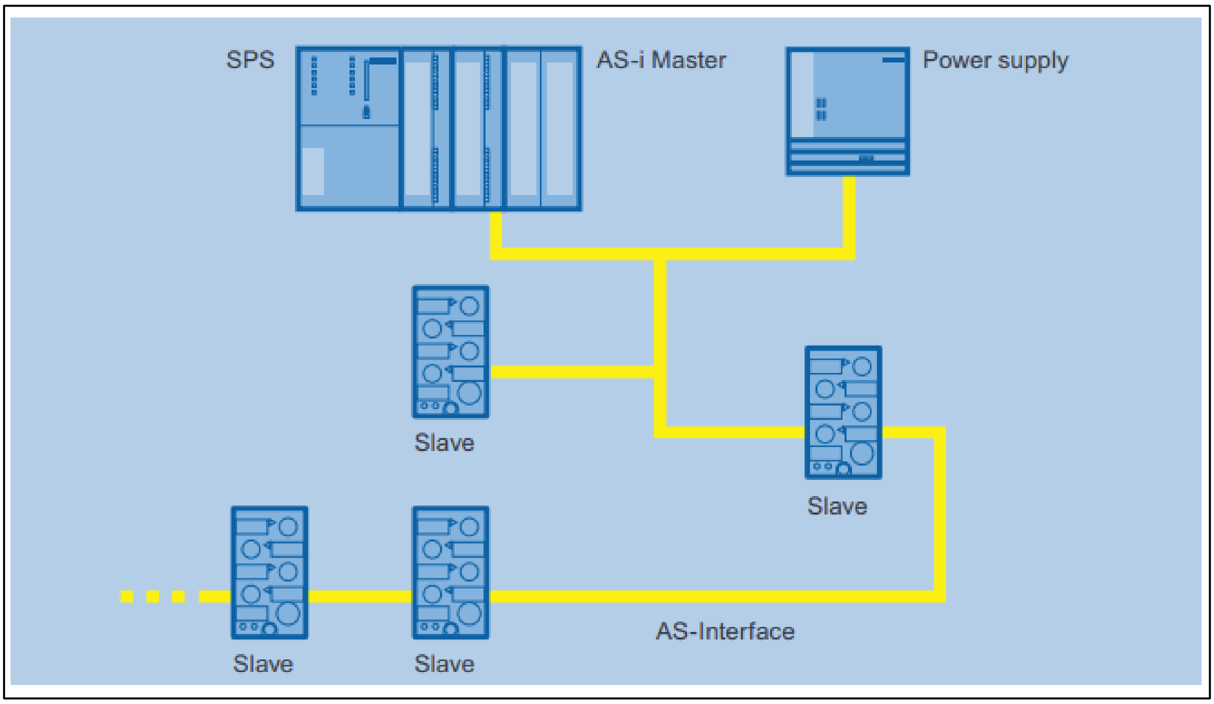


Figure 21: AS-i communication service[43]

- **Wide Area Network (WAN)**

Typically, a Siemens Network Automation (SINAUT) system is a geographically dispersed system. It is comprised of stations, potential node terminals, and one or more control centers. The components of the system are linked via suitable data transfer media. Exclusively adapted communications processors for SINAUT system ensure secure data transfer using a network-specific protocol. Data that cannot be lost in the event of transmission path failures or partner failure are saved and sent after the issue has been resolved. Some Simatic control systems can be extended to a SINAUT station with the addition of suitable SINAUT module to it.[43]

The Classical WAN which are used for data transmission are as follows-

  - Private radio networks
  - Dedicated lines, it can be private or leased
  - Analog telephone network
  - Mobile radio network

- **Multi-Point Interface (MPI)**

MPI is the integrated interface of SIMATIC products. That includes Controllers, Panels and devices used for programming as in PC. MPI is PROFIBUS standard based which supports topologies such as Line, star, tree.[43]

<u>Basic Principles-</u> A simple network capability with the help of following services is provided by MPI:

  - S7 Communication
  - S7 Basic Communication
  - Global Data Communication (GD)

S7 is a type of controller present in siemens controller library. 187.5kbps to 12Mbps is the baud rate which MPI Supports. The PC programming device is used to set the MPI node addresses, which must be unique.[43]

<u>Connection System-</u> The connection of nodes to the MPI network is in the following manner:

- Programming devices/PCs and panels are linked via connecting wires.
- The PROFIBUS bus line is connected to the MPI interface of the controllers' CPUs through a bus connector. [43]

- **Point to Point Interface (PPI)**

SIMATIC controller model S7-200, for that particular model PPI is developed. It is used to connect S7-200 devices. But other SIMATIC controllers such as S7-300, S7-400 along with operator panels they all can hold communication in PPI network.[43]

Basic principle- PPI is a master-slave protocol wherein master devices transmit requests to slave devices. Slave devices wait until a master device makes a request or polls for a response before initiating communications. The connection utilized for communication is a standard PPI link.[43]

Master Devices are for example:

- Programming devices with STEP7. STEP7 is a tool for configuration and programming of SIMATIC controllers.
- HMI devices like touch panels, operator panels

Slave Devices include:

- S7-200 CPU
- Expansion racks

S7-200 CPUs can also be programmed to function as PPI masters.

There exist three other network systems named as Industrial Ethernet, PROFIBUS, PROFINET and they are discussed in next sub-chapter with the support of SIMATIC system.

➢ **OPC Communication Platform**

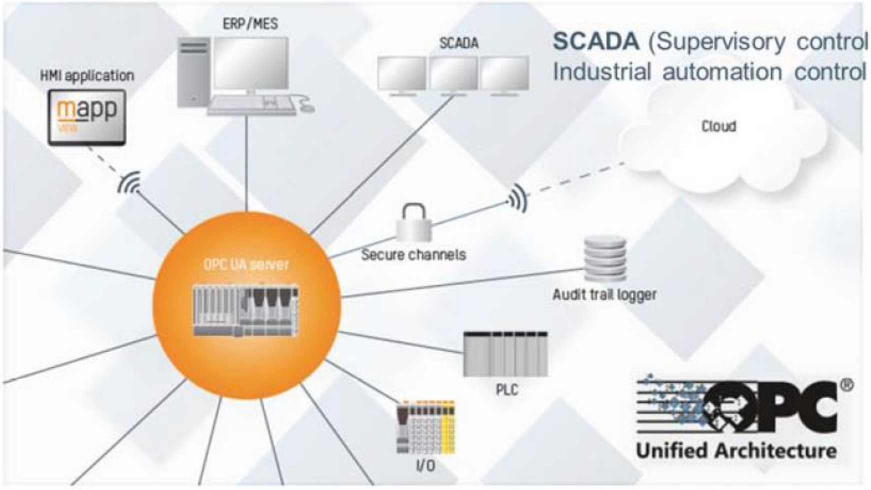


Figure 22: OPC UA Industrial Communication Standard- state-of-the-art Automation Backbone[44]

The Open Platform Communication Unified Architecture (OPC UA) Figure 22 launched in 2008, is a platform-independent service-oriented architecture that unifies all the capabilities of the separate OPC Classic standards into a single expandable framework. OPC UA is beneficial for implementing the Industrial M2M Communication Protocol. It has the interoperability attribute (ERP, Cloud -Machine-Level). It is independent and adheres to an open standard. In addition to these benefits, it includes Intrinsic Security Features.[44]

2.3 SCADA System Specification

Specification of SCADA system varies according to the system in which they are being applied. Here below a case of Siemens SCADA system is considered. Any system should be designed keeping in mind all the necessary protocols. If the following of protocols, it makes interchangeability and integration easier. Communication of RTU with all the sensors and relays should fulfil all the necessary functionalities without any issues. When SCADA system specification needs to define it can be defined keeping any one SCADA system in mind. And for fundamentals understanding purpose SIMATIC SCADA system is considered. It can be seen in Figure 25.

2.3.1 SIMATIC Automation System

SIMATIC Technology provides a broad, scalable hardware range across many classes of performance with integrated technology solutions for optimal flexibility and integration. Highest level of productivity is attained if integrated together with Totally Integrated Automation (TIA) portal. Users can quickly parameterize technological items as opposed to needing to program sophisticated technologies. On the hardware side, the technical functions are effectively supported by technology modules.

Single or multiple axes drive systems can be easily and efficiently controlled by using SIMATIC function integrated motion control. The Motion Control instructions necessary for programming sequences of movements which are based on the standards defined by PLCopen, allowing Motion Control applications needs to be programmed without requiring any specialized knowledge. The signal acquisitions are immediate, and system has precise response. Specialized modules permit the acquisition and transmission of signals with a 1 microsecond resolution. This is beneficial when both the product quality and output is considered. SIMATIC controllers are implemented with control function so to perform automation tasks. Therefore, no special control hardware is needed. A two-stage integrated auto-tuning procedure guarantees that the control parameters are optimally set. Additionally with the bus systems like PROFINET IO and PROFIBUS DP, the serial point-to-point or multi-point connections could also be applied for data transmission in automation. Protocols and Multiple physical interfaces enable communicating with non-system components for example, scales, meters, and others, ensuring a high degree of flexibility.[45], [46]

2.3.2 Siemens SIMATIC Controller

Three different controllers are present in the system shown in Figure 25. As can be seen in Figure 23 the controllers are varied according to the criteria of performance and according to the complexity of the application. If superficially noticed it can be said that bigger the model number of controller better the performance of that controller. The controllers seen in Figure 25 and the are namely S7-300, S7-400 and S7-1500. Every controller is unique as far as the features are concerned. They are releases one by one and each one is an upgraded version of previous one.

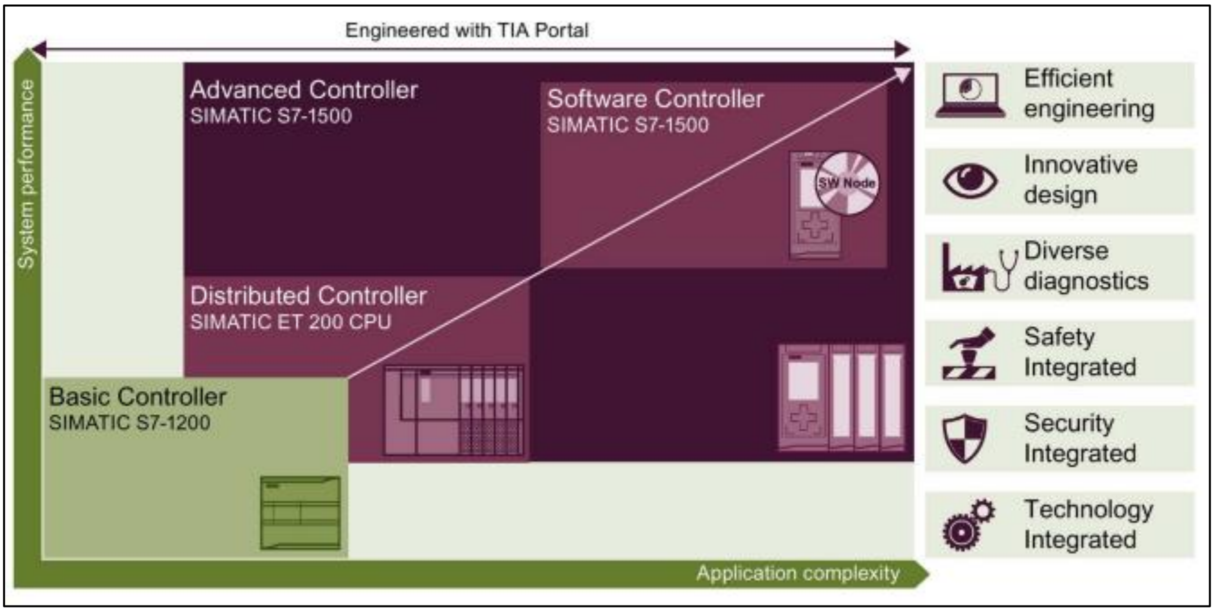


Figure 23: Overview of SIMATIC automation system[47]

2.3.2.1 Difference between SIMATIC Controller models

To justify the point of SCADA system specification one siemens SIMATIC system example is considered as expressed in Figure 25. The controllers exist are S7-300, S7-400, S7-1500.

The main difference between these three controllers is their performance. The S1500 is used for high performance applications as compared to the S7-300 and S7-400. S7-1500 have the less reaction times, faster backplane bus and standard Profinet interface over S300 and S400 controller. In real world the programming speed doesn’t really matter but when any process being carried out in assembly line processing makes very big difference. S7-1500 has display which come as a standard which can be used for easy configuration without needs of tools.[48]

For S7-1500 CPU comes with two Profinet ports as standard and then additional ports and communication protocols can be selected when ordering. In addition, these ports could be configured as a bridge then which acta as a mini switch. In contrary, for S7-300 and S7-400 necessary number of ports along with communication protocols needs to be chosen while ordering.[48] High speed counters are present for counting and measuring at S7-1500 and in opposite in S7-300 and S7-400 there doesn’t exist high speed counters.[49]

If the communication point of view is concerned S7- 400 is superior that rest two types of controllers. It is because, it can initiate when needed a warm or cold start and at remote device, it can initiate remote device restart, it can send data to the printers, remote device status change it can receive. Managing communication connection with receiving data using Ethernet or Profibus is possible only with S7-1500 controller. [49] For understanding purpose one controller that is S7-1500 has been taken into account in further section.

2.3.2.2 SIMATIC S7-1500 Controller

The SIMATIC S7-1500 is an advancement of the automation system SIMATIC S7-300 and S7-400. By incorporating various new performance characteristics, the S7-1500 automation system provides the user with superior operability and the best performance. The main important features are- high performance, motion control integrated functionality, integrated HMI for observation of operations as well as troubleshooting. On a mounting rail, the S7-1500 automation system can hold up to 32 modules. The modules are interconnected using U connections.[45], [50]

➢ **Components of SIMATIC S7-1500 Controller**

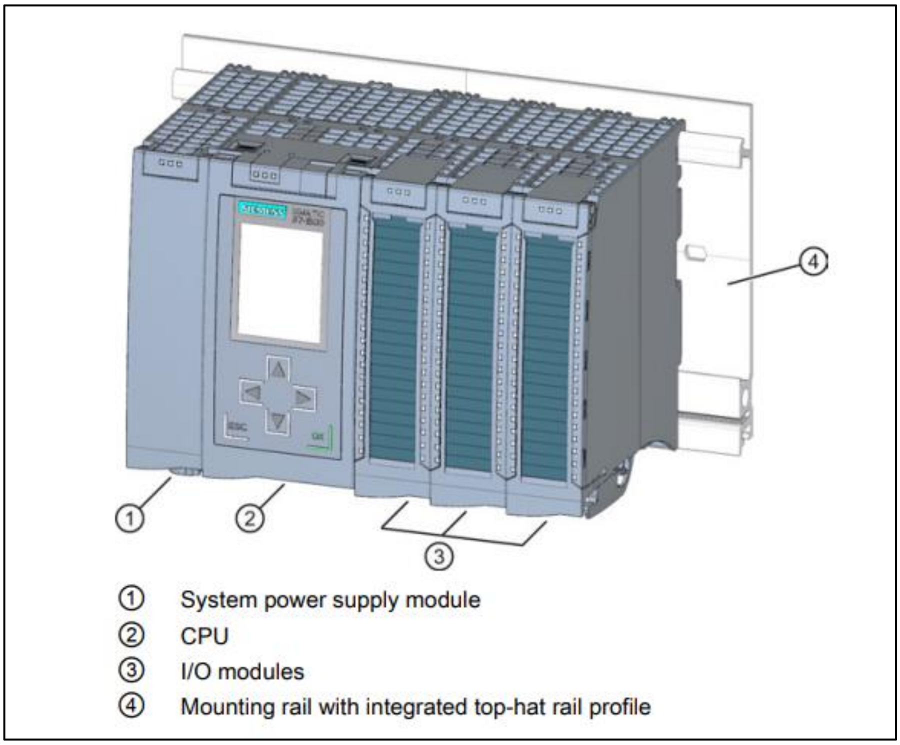


Figure 24:SIMATIC S7-1500 System[45]

The components of SIMATIC S7-1500 are mentioned in Figure 24.

- **System Power Supply Module-** The capability of system power supply module is it can carry out diagnostic. And using U connector it can be connected with the backplane bus. If the power given from CPU into backplane bus which is not enough to continue supply modules connected with power, then a system power supply is necessary. Various models are available for system supply such as, PS 60W 24/48/60V DC, PS 25W 24V DC, PS 60W 120/230V AC/DC. If the system power supply is ordered in that package power cable with coded element as well as U connector is included. Function of U connector is to be providing electrical and mechanical connection between modules. [45], [50]
  The specifications include different technical aspects such as how much the output voltage should be, On/Off behaviour, how the notifications are displayed. It also includes efficiency as well as power loss.[51]
- **CPU-** CPU is the one which executes the program and then utilizes system power supply for supplying the electronics of the module through the bankplane bus. CPU has many features such as it can be connected via ethernet. The communication is possible via PROFIBUS OR PROFINET. It can have ideal HMI connection. It holds integrated web server. It has integrated system diagnostics.[45]
  There exist different models of CPU those are based on programming requirement or how much data is needed to be stored. On CPU type it depends how the processing speed will be. But for the operation of CPU SIMATIC, memory card is required.[51] The CPU's technical specifications include if it is used for a single function or if it will be multi-functional, how much memory it holds, how many I/O ports it holds. [51]
- **I/O Module-** I/O modules act as a bridge between controller and actual process. The triggers used, sensors used, and actuators used gives signal to controllers and then it detects what current process state in the system is. I/O modules are divided into different types of modules:[45], [50]
  - Digital Input (DI)
  - Digital Output (DQ)
  - Digital Input/Digital Output (DI/DQ)
  - Analog Input (AI)
  - Analog Output (AO)

- Communication Module (CM)
- Communication Processor (CP)

The specification criterions are what kind of module it is for ex. DI, DQ or DI/DQ etc., at what temperature it operates, what kind of supply it is being provided with, how much mechanical stress it can handle etc.[51]

- **Mounting rail with integrated top-hat rail profile-** Racking components for the S7-1500 automation system are housed on the mounting rail. Mounting additional system parts (modules from the S7-1200 along with ET 200SP terminals, circuit breakers, ranges, small contactors, or other components of a similar nature) straight on top of integrated standard mounting rail that is located in the lower portion of the mounting rail is possible. In the assembly (which is called a margin less assembly), users are free to use the complete length of the mounting rail.[45]

One of the important properties of S7-1500 controller is, it provides fail-safe reading of sensor information and also works from -25 to + 60 degree Celsius. It can be operated at altitude as high as 5000m as standard. SIMATIC S7-1500 complies with many national and international standards namely cULus approval, cULus HazLoc approval, KCC, FM approval En61131-2 etc. It has 4 internal sensor supplies on-board including test function. It consists of LED display used for error, operation, supply voltage also the status. For powerful connection PROFINET IO (2-port switch) is used as standard interface. SIMATIC S7-1500 can be easily connected to non-Siemens devices/systems by using OPC UA server (data access) with the client as a runtime option.[52]

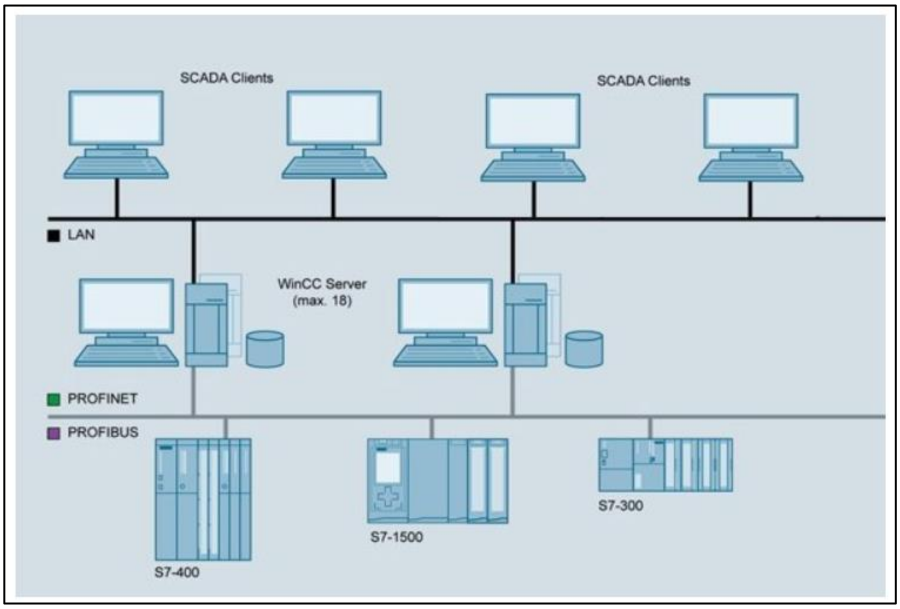


Figure 25: Siemens SCADA System Specification [53]

2.3.3 SIMATIC S7 Controller Communication

Through the use of a controller, the S7 communication protocol is able to route data among PROFINET and PROFIBUS. Current S7-300/400 systems can be connected to S7-1500 via S7 communication, or existing systems can be migrated to S7-1200/1500. Utilize open communication for data interchange between S7-1500 and, as a result, the various possibilities offered by common Ethernet protocols.[49]

2.3.3.1 PROFIBUS Communication

PROFIBUS is a fieldbus system that meets the criteria for intelligent field device connectivity in industrial, process, and building automation. It networks field devices to the automation system. The various communication networks can be utilized independently or in conjunction with one another. The PROFIBUS Specification that defines the technical and functional characteristics of a serial fieldbus is intended for the interconnection of low or medium performance digital field devices or systems, such as sensors, switches, actuators, transmitters, programmable logical controllers (PLC), numerical controllers (NC), programming devices along with local man machine interfaces, and so on. Typically, a field control system is comprised of a central control and supervisory unit coupled to a number of distributed devices and small systems. [54][55] If the length of copper cables is not sufficient in the networking, then the network can be expanded by using repeaters and it can be seen in Figure 26.

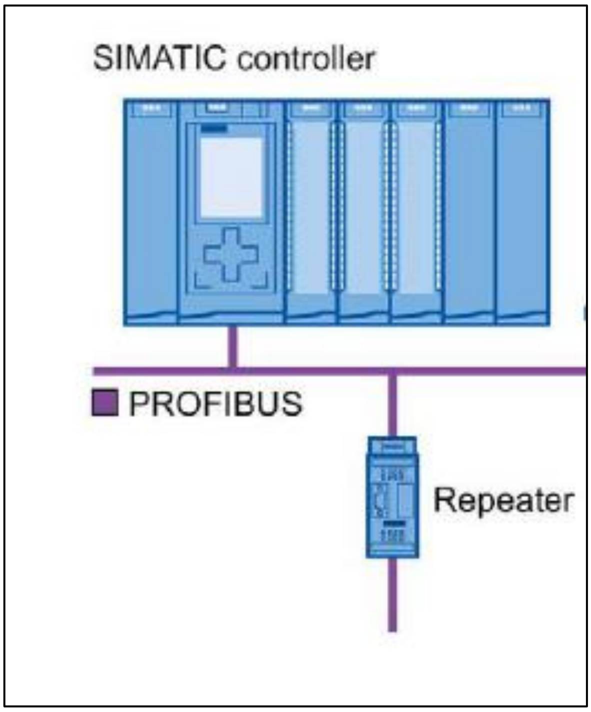


Figure 26: PROFIBUS Network[55]

- **PROFIBUS Protocols**
  - **PROFIBUS DP (Distributed I/O)**

PROFIBUS DP, which stands for "distributed I/O," is a communication network system for the field scale that complies with IEC 61158-2 and EN 61158-2 and uses the hybrid access protocols token bus together with master-slave. In order to accomplish the networking, either two-wire lines or fiber-optic cables are utilized. It is feasible to achieve data transfer rates ranging from 9.6 kbps to 12 Mbps.[55]

  - **PROFIBUS PA**

The PROFIBUS used for process automation is known as PROFIBUS PA (PA). It does this by bridging the gap between the MBP (Manchester Bus Powered) transmission technology and the PROFIBUS DP communication protocol that is required by IEC 61158-2. It is possible for PROFIBUS PA networks to be created on the basis of shielded, twisted two-wire lines that are intrinsically safe, making them appropriate for use in hazardous situations (Ex zones 0 and 1). The speed of the data transmission is 31,25 kbps per second.[55]

Halfduplex transmission is the standard. The mode of transportation via bus is a hybrid one. Data is sent with or without acknowledgement using a data transmission service. Each frame can have a length of between 1 and 255 bytes. Data integrity Message with hamming distance HD 4. In terms of bandwidth, Cat 3, Cat5, Cat5e, Cat6, Cat6a, etc. are some of the several versions of Ethernet. [54], [56]

- **PROFIBUS Fastconnect (FC) System**

PROFIBUS FastConnect is a method that enables the manufacture of PROFIBUS copper wires in a quick and straightforward manner. There exist the three parts that comprise the system: a FastConnect stripping tool, a FastConnect bus connector for PROFIBUS with insulation displacement mechanism, and FastConnect bus cables for rapid mounting.[55]

Because of the unique construction of the FastConnect bus cables, the FastConnect stripping tool may be used to remove the protective jacket and also the braided shield in a single step. This ensures that the protective jacket is removed properly. The insulation displacement method is utilized in order to successfully complete the connection of the prepared wires within the FastConnect bus connectors. All PROFIBUS FastConnect bus cables may also be linked to the standard bus connectors using screw-type terminals. This connectivity option is available for all PROFIBUS FastConnect bus cables.[55]

2.3.3.2 Profinet Communication

Profinet is further development of fieldbus IO that is PROFIBUS DP and Ethernet, and it is used for industrial networking and communication purpose. It has transmission rate up to 100mbps and mode is full duplex. It has advantage of simple and cheap cable connection. The redundant S7-1500R/H system exchanges IO data with the IO devices on a cyclical basis. Horizontal Synchronization Forwarding allows a PROFINET device with Media Redundancy

Protocol (MRP) to forward S7-1500R redundant system synchronization data (synchronization frames) solely inside the PROFINET ring. [57]

Objectives of PROFINET include:[57]

- It serves purpose of industrial networking which is based on Industrial ethernet.
- IT has real-time working competence
- With PROFINET it is flawless combination with other fieldbus system
- It is industrial level, so it holds high robustness. They are very well compatible with industrial environment.

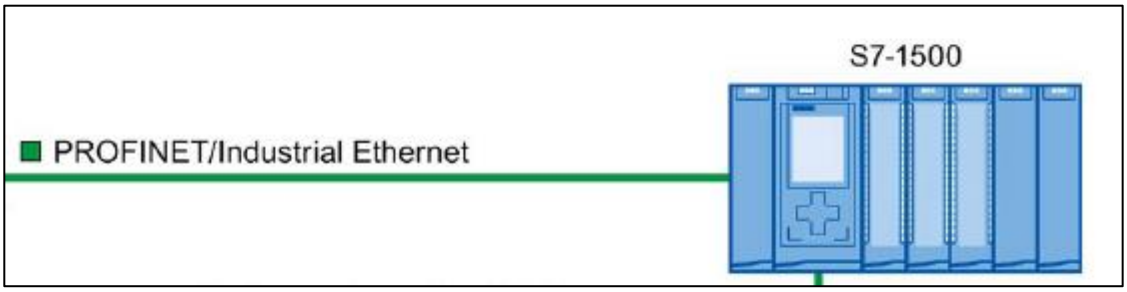


Figure 27: PROFINET Connection with S7-1500[57]

- **Communication Using Profinet I/O**

Field devices communication is possible with the use of PROFINET. The communication between controllers, devices and CPU is addressed.

- **Communication between IO controller and IO Devices-** The IO controller transmits and receives data cyclically with the IO devices of its PROFINET IO system.[57]
- **Communication between IO controller and I-device-** A constant amount of data is cycled between the user applications in the CPUs of IO controllers as well as I-devices. The IO controller does not address the I/O module of the I-device; rather, it addresses defined address ranges, i.e. transfer ranges, which may be situated within or outside the process image of the CPU of the I-device's If portions of the process image are utilized as transfer ranges, these cannot be used for actual I/O modules. Data transfer occurs utilizing load- and transfer-based activities or direct access to the process image.[57]

- **Communication between IO controller and IO controller (PN7PN coupler)-** A defined amount of data is exchanged cyclically between user applications in CPUs of IO controllers. As a supplementary hardware A PN/PN coupler is needed. A PN/PN coupler eases data transfer between two controllers.

  The IO controllers mutually access specified address ranges, also known as transfer ranges, which may be situated within or outside of the CPU's process image. If portions of the process image are utilized as transfer ranges, these cannot be used for actual I/O modules. Data transfer occurs utilizing load- and transfer-based activities or direct access to the process image. I/O communication is allowed between two PROFINET IO systems using a PN/PN coupler.[57]

- **Communication between S7-1500-CPU and S7-1500-CPU (Direct data exchange)-** An S7-1500 CPU will transmit cyclic user data gathered from the I/O area to one or even more partners in the event that direct data exchange is utilized. The direct data exchange utilization is based on PROFINET's IRT protocol and isochronous mode. Transfer areas carry out process of the data exchange.[57]

- **Linking PROFINET with Profibus**

PROFINET is easier to connect PROFIBUS and it has been made possible with IE/PB link. One is able to merge pre-existing PROFIBUS configurations into the PROFINET configuration if there exist a proxy capable PROFINET device and which is also equipped with a PROFINET interface in combination to a PROFIBUS interface (for example, an IE/PB Link PN IO). It is mentioned in Figure 28. ET 200SP is a remote I/O unit where it connects sensors and actuators to the controller, and it is one of the popular remote I/O devices. ET200M is also another type of I/O device which is used as a bridge between sensors, switches to the controller. It has high density application which is exclusively used for SIMATIC S7-300. [58], [59][57]

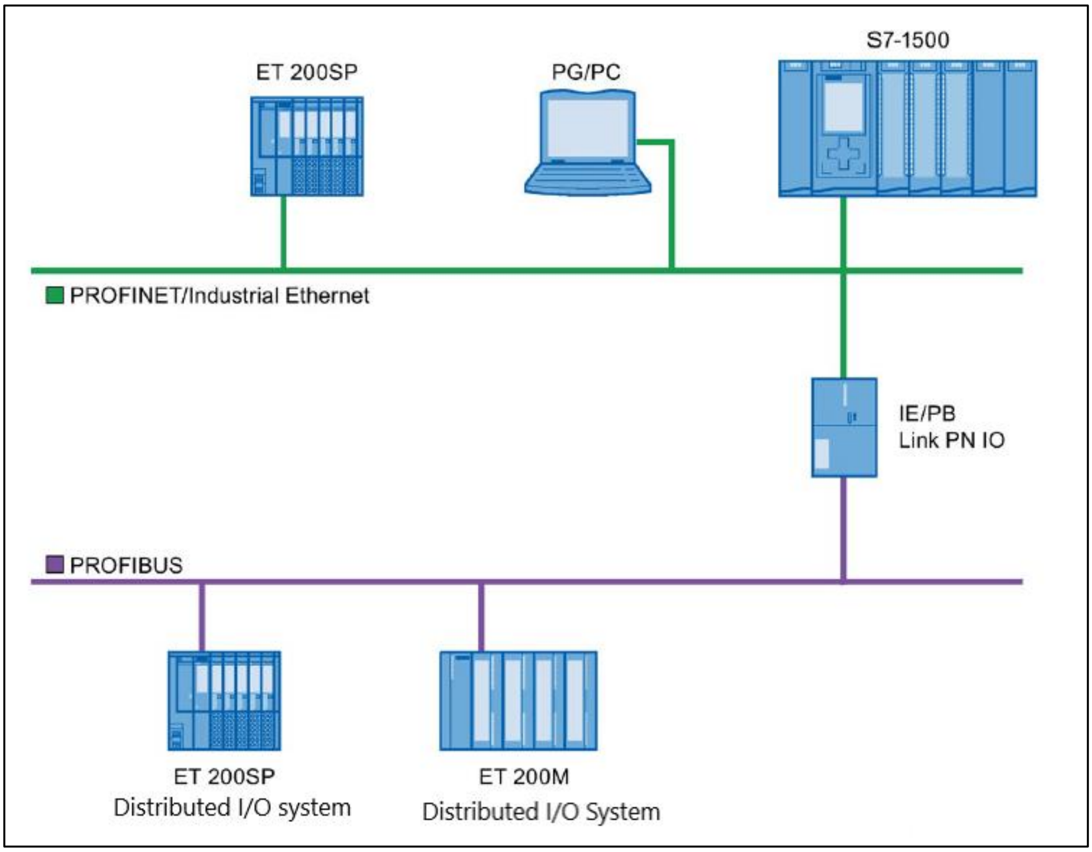


Figure 28: Linking of PROFINET and PROFIBUS[57]

PROFINET also exist proxy functionality. PROFINET device which holds proxy functionality can replace PROFIBUS device based on Ethernet. With proxy functionality it makes easier for PROFIBUS devices to communicate with devices on PROFINET as well as obviously master.

2.3.3.3 LAN Network Communication

Local Area Network (LAN) is a network which comes under category of "Industrial Ethernet" and follows Ethernet standard IEE 802. This provides deterministic transmission of data. The ethernet should fulfil the industrial need for what it is being used for along with keeping operations uninterrupted in extreme climatic conditions. It is used for connection from controllers to the HMI or personal computer in the SIMATIC system. [60]

- **WLAN-** Wireless Local Area Network is a next advancement of LAN networking. Using of LAN hard wired cables have numerous advantages as it makes availability of an exclusive medium. But with complex system architecture the network keeps growing and with increased networking it comes the complexity in wiring, the costing of LAN networking also reaches new highs because of a greater number of nodes. With WLAN along with benefit in customer satisfaction it also benefits in the areas where actual LAN networking is not possible.[60]

2.3.4 SIMATIC WinCC Server

SIMATIC WinCC RT Professional in combination with SIMATIC Industrial PCs constitute a high-performance and versatile platform for data acquisition, assessment, and visualization. WinCC can be used to set up client/server systems with more than one client and server. This makes it easier to run and monitor complex systems. By splitting up the tasks of running and keeping an eye on processes across multiple servers, the rate at which each server is being used reduced, which improves performance. Additionally, it is possible to map systems with a complicated technological or topological structure using WinCC. Thus, one can count on synchronized development and end-to-end integration of software and hardware, which pays dividends throughout the product's life cycle.[61][62]

Where there are number of monitoring stations are needed at that places the WinCC system is placed. It is also placed where monitoring and operating tasks are divided to various operating stations so for displaying notifications of one system.

2.3.4.1 WinCC Communication Structure

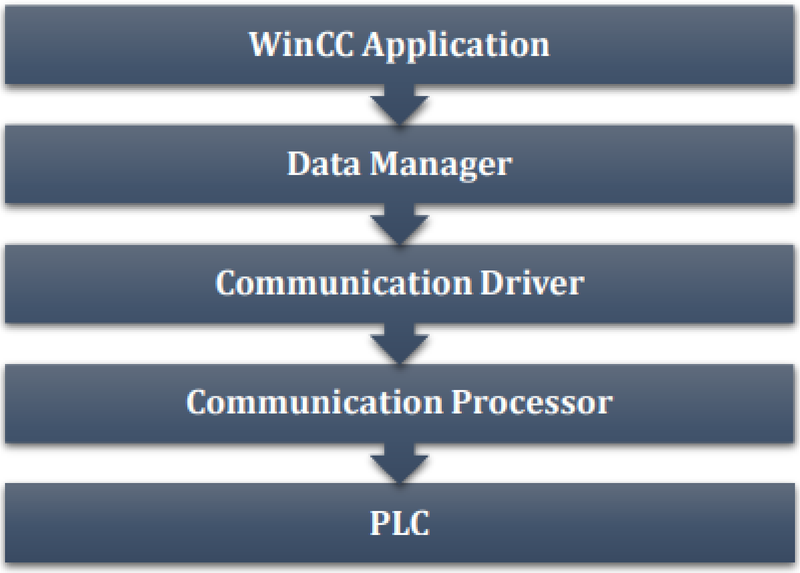


Figure 29: WinCC Communication Structure

Data Manager- Unobservable to users, data manager is the WinCC data handle mechanism. All WinCC Runtime programs, including tag logging and alarm logging, are required to request WinCC tags from the data manager.

Communication Driver- Communication drivers in WinCC establish communication between the data manager and the PLC via several channels. Each accessible communication driver is a Dynamic Link Library (DLL) that communicates via Application Programming Interface with the data manager (API). Each channel of communication within a communication driver may have its own protocol for communication.

Communication Processor- The communication processor offers an interface for a PC to detect specific communication protocols and facilitates the exchange of data with an automation system. [63]

2.3.4.2 WinCC Redundancy

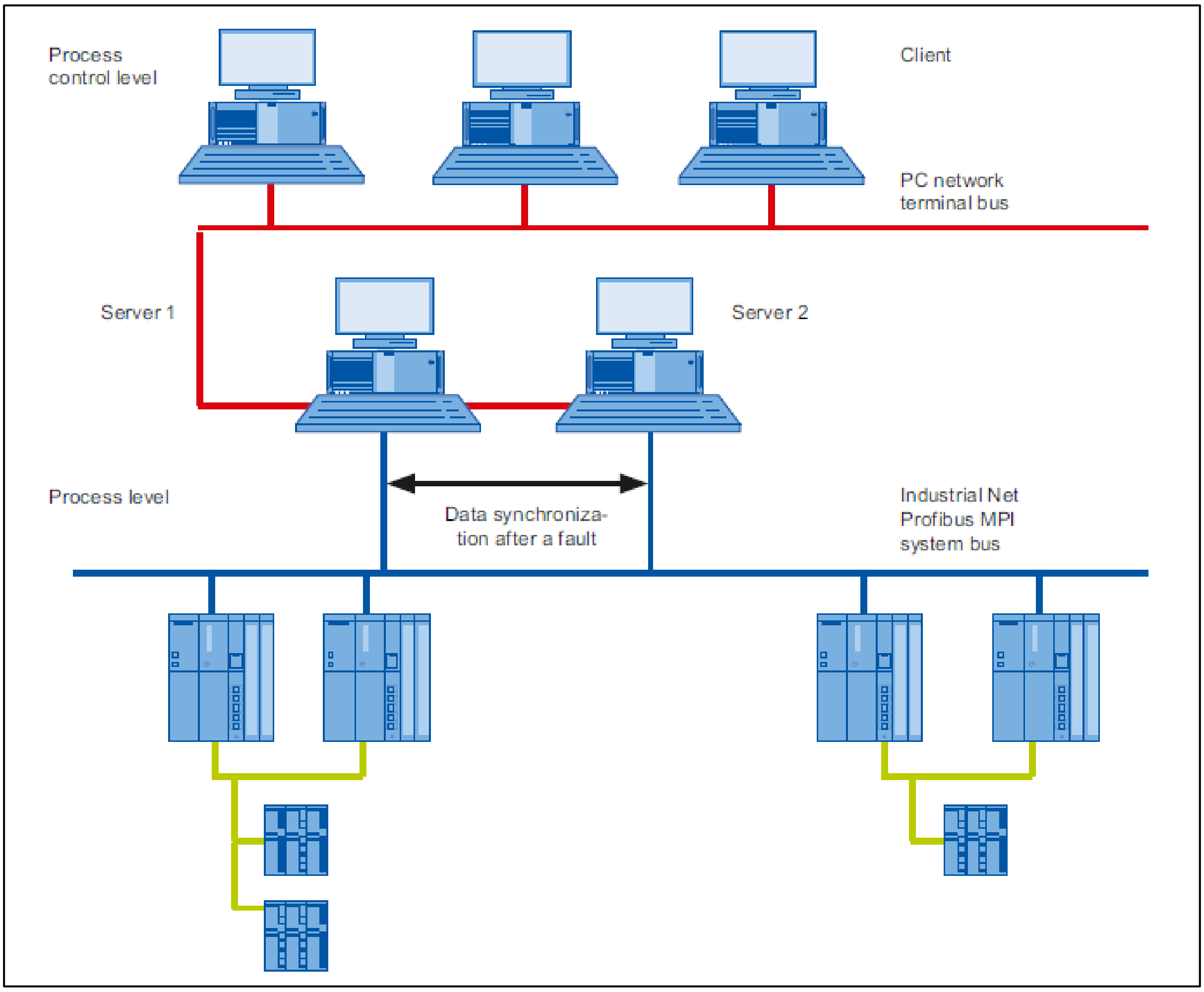


Figure 30: WinCC Redundancy Concept Explanation[62]

A depicted redundant WinCC project in Figure 30 is comprised of two WinCC servers designed to execute identical activities and operate in parallel. It can be seen that a master server and a standby server exist. The two servers are linked to the automation system, the clients, and to one another.[62]

<u>The functions provided by WinCC redundancy server are</u>[62]<u>-</u>

- It should serve the purpose of serving client after failure of first server by switching to second server.
- Internal messages are synchronized online.

- After the failed server is recovered there should be automatic synchronization of client data, process value archives, message archives.
- "Project Duplicator" used to copy crated project to the redundant server
- WinCC application health check-up is done by "Application Health Check"
- Hardware and Software local system is monitored by "SelfDiagnosis" function.

- **Application Health Check Function**

It is a function which monitors automatically all WinCC applications. If any software error is observed server status changes from "@RedundantServerState" to "Fault". And then it allows operator to switch to the another which is Redundant server. Using a process control message to communicate the program error to the user. A process control message which cannot be generated if the failure was caused by the alarm server.[62]

- **SelfDiagnosis Function**

The SelfDiagnosis function incorporates the aforementioned responsibilities in order to guarantee the system's availability and stability[62]-

- To monitor and to report local HW and SW problems.
- Monitoring the performance of local system
- Monitoring the data volume state

And if malfunction is observed then following tasks are carried out.

- Restarting the application
- If fault occurred, then changing it to the next server
- Triggering of system alarm
- Generation of log entry

WinCC plays vital role in SIMATIC SCADA system setting up. Because of which the SCADA system can do task of data acquisition within secure working environment. Because of its capacity it to handle number of clients at the same time and quick performance strengthens the overall SIMATIC SCADA system with series of other advantages.

All the SCADA systems are designed keeping various international standards keeping in account. Those standards can either designed by PLC, IEC or number of other organisations. And those make the SCADA system easier to comprehend by different individuals and then perform interchangeability. Further sub-chapter is created to give more idea about SCADA standards available.

2.4 Standards of SCADA System

The RTU takes orders to operate control points, adjusts analog output levels, and reacts to requests in a SCADA system. Status, analog, and cumulative data are sent to the SCADA master station. The sent data representations are not recognized in any way other than by their unique addresses. The addressing is designed to correspond with the database of the SCADA master station. The RTU is unaware of the specific parameters it is measuring in the physical world. It only monitors certain locations and saves the data in a local addressing system. The SCADA master computer is the component of the system that should "understand" that the first status point of RTU represents the state of a particular circuit breaker at a specified substation. These are the prevalent SCADA systems and protocols utilized in the utility business today. Each protocol consists of two sets or pairs of messages. One set is the master protocol, which contains legitimate statements for master station initiation, and also the other set is the RTU protocol, which contains valid statements that an RTU can begin and react to. In the majority of circumstances, but not all, these pairings can be interpreted as a request for information or action, and a confirmation answer.[64], [65]

The SCADA protocol between master and RTU serves as an effective paradigm for RTU-to-Intelligent Electronic Device (IED) connections. There are now various distinct protocols in use in industry. IEC 60870-5 series, particularly IEC 60870-5-101 (often abbreviated as 101), and Distributed Network Protocol version 3 are the most prevalent (DNP3). [64]

2.4.1 HMI Ergonomic Standards

SCADA enables remote monitoring and control of industrial operations and helps offer field-level input in real time (sensors and actuators). HMI is informing the operator about the activities. Considering human well-being, user satisfaction, ergonomics, guidance on accessibility for HMI interface there are various standards available in the industry such as ISO 11064, ISO 9241 etc. [66]

2.4.1.1 ISO 11064 Ergonomic Design for Control Centers

The ISO 11064 standard specifies the design concepts, suggestions, and standards for control centers. The ISO 11064 series' principles, guidelines, and criteria can assist users with:

The ISO 11064 series' principles, guidelines, and criteria can assist users with:

- User consultation
- Aligning functional design with purpose
- Avoiding abortive design and needless revisions
- Aiding in the organization of multidisciplinary teams
- Reducing the mistiming of crucial stakeholder contributions [67]

This standard presents characteristics for both broad application and specialised use in industrial control rooms. Physical ergonomics is the primary application of ergonomics. This standard is organized into the following five fundamental sections[68]:

- Part 1: Design principles for control centers
- Part 2: Design principles for management control rooms and annexes
- Part 3: Control room layout
- Part 4: Job distribution and size
- Part 5: Displays and controls

Part 5 covers ergonomic concepts, rules, and suggestions on indicators and controls, as well as their interaction in the hardware and software design of control centre hardware and software[68].

2.4.1.2 ISO 9241 Ergonomic of Human Interaction Standard

The European Committee for Standardization, in alliance with the International Organization for Standardization (ISO), promoted the development of ISO 9241 in order to prevent possible physical disorders such as musculoskeletal, and vision problems, as well as fatigue, and in consideration of ergonomic studies.[66] The information contained in ISO 9241 tackles technical human factors and ergonomics concerns just to the level required for such individuals to comprehend their relevance and significance in the context of the entire design process. In addition, it provides a framework for human factors and usability experts interested in human-centred design.[69] Regardless of the design process and distribution of tasks and roles, a human-centred approach should adhere to the following principles-

- The design is based on an explicit understanding of users, tasks and environments
- Users are involved throughout design and also development
- The design is driven and refined by user-centred evaluation
- The process is iterative
- The design addresses the whole user experience
- The design team includes multidisciplinary skills and perspectives

Products, systems, and services should be created with keeping users and other stakeholder groups in mind, especially those who may be directly or indirectly affected by their usage. One of the biggest causes of system failure is the construction of systems based on an incorrect or partial knowledge of user demands. Involving users in design and development is a vital source of information on the context of usage, the tasks, and the anticipated manner in which users will interact with the final product, system, or service. In human-centred design, user feedback is an essential source of data. Evaluating designs with users and revising them based on their comments is an effective way to reduce the risk of a system failing to fulfil user or organizational requirements. The point process iteration indicates that descriptions, specifications, and prototypes are amended and modified as new information is available to reduce the possibility that the system under development would fail to fulfil user needs. Considering organizational implications, user documentation, on-line assistance, troubleshooting and maintenance (with help desks and customer contact points), training, long-term usage, and product packaging (including the "out-of-the-box experience") while designing for the user's experience. Human-centred design teams need not be huge, but they must be sufficiently diversified to cooperate on design and implementation trade-off considerations at the right moments. [69]

The following principles of design has to be taken into account according to ISO 9241-110 for interactive system[69]-

- If suitable for the task
- Self-descriptiveness
- Conformity with expectation of user
- Suitability for learning
- Controllability
- Suitability for individualization
- Error tolerance

Above all mentioned points are to be considered while designing any HMI system. [69]

2.4.2 IEC 60870-5 Telecontrol Communication Standard

IEC 60870 standard is the one which specifies SCADA telecontrol system components. Part 5 offers a communication profile for the transmission of fundamental telecontrol signals between two systems using permanent, directly connected data connections.[70] The IEC 60870-5 protocol stack is based on the "Enhanced Performance Architecture" reference model reduction (EPA). This architecture is comprised of solely the physical, link, and application layers of the ISO OSI model. The following standard publications Table 1 outline the IEC 60870-5 protocol. [71]

This user layer provides compatibility for clock synchronization and file transfer capabilities. The descriptions that follow outline the fundamental breadth of each of the five publications comprising the IEC 60870-5 base telecontrol transmission protocol standard set. Standardized profiles are required for the universal implementation of IEC 60870-5 standards. A profile is a collection of settings that define the behaviour of a device. These profiles have been and continue to be generated. The 101 profile is explained in detail where the necessary standards are given.[64]

Table 1: Selected standard provision of the defined telecontrol companion [71]

<table>
<tr><td>Selected application functions of
IEC 60870-5-5</td><td>User Process</td></tr>
<tr><td>Selected application information elements of
IEC 60870-5-4</td><td rowspan="2">Application layer (Position 7)</td></tr>
<tr><td>Selected application service data units of
IEC 60870-5-3</td></tr>
<tr><td>Selected link transmission procedures of
IEC 60870-5-2</td><td rowspan="2">Link layer (Position 2)</td></tr>
<tr><td>Selected transmission frame formats of
IEC 60870-5-1</td></tr>
<tr><td>Selected ITU-T recommendations</td><td>Physical layer (Position 1)</td></tr>
</table>

- IEC 60870-5-1 provides the fundamental standards for services to be delivered by the data connection and physical layers in telecontrol systems. Specifically, it sets standards for encoding, formatting, synchronizing data frames of variable as well as fixed lengths that satisfy specified data integrity criteria.
- IEC-60870-5-2 (1992-04) specifies a variety of link transmission protocols employing a control field and optional address field; the address field is optional since certain topologies that are point-to-point do not require source or destination addressing.

- IEC 60870-5-3 defines guidelines for arranging application data units inside transmission frames of telecontrol systems. These guidelines are offered as generic standards that may be used to support a wide range of existing and future telecontrol applications. This part of IEC 60870-5 specifies the fundamental structure of application data and the basic principles for describing application data units but does not specify the contents of information fields.
- IEC 60870-5-4 (2003-08) specifies standards for establishing information data elements and a information set elements, which also includes digital and analog process variables which are often used in telecontrol applications.
- IEC 60870-5-5 (1996) provides the fundamental application functions that execute standard procedures for telecontrol systems. These are procedures that exist above layer 7 (application layer) of ISO reference model. These leverage typical application layer services. The IEC 60870-5-5 (1995-06) requirements serve as the foundational standards for application profiles, which are subsequently developed in detail for particular telecontrol activities.[64]

Each application profile will utilize a certain subset of the stated functionalities. Any fundamental application functions not included in a standards document that are required to define particular telecontrol applications should be provided inside the profile. Station initialisation, cyclic data transmission, data collecting via polling, clock synchronization, and station setup are examples of such telecontrol functions. The Standard 101 Profile contains structures that are also directly relevant to the RTU-IED interface. It provides all the protocol elements required to offer a clear specification of the profile, allowing manufacturers to design completely interoperable products. [64]

2.4.3 IEC 61161-3 Standard for PLC Programming

IEC 61131-3 is a standard because of which the PLC programming languages got standardized and it help particularly to standardize programming language which has been used for industrial automation. If the standard has been split into two parts, it makes concept understanding easier. And the two parts are common elements and programming languages.[72]

2.4.3.1 Common Elements

- **Data typing-** Data types are defined within common elements. Errors in early stages are being prevented by data typing. Mostly used data types are integer, Boolean, enum, byte, word also string, date, Time_of_day. Also, on the basis of mentioned data types one can derive his own personal data type. So, for example if one digital input channel is considered as a data type someone then they can use it again and again.

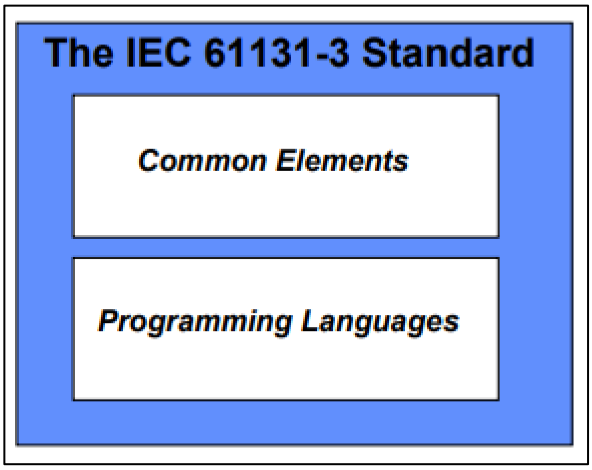


Figure 31: IEC 61131-3 Standard division

- **Variables-** Only explicit hardware addresses (such as inputs and outputs) can have variables assigned to them in configurations, resources, or programs. As a result, a high level of independence from the underlying hardware is established, which strengthens the reusability of the software. In most cases, the scopes of the variables are restricted to the organizational unit in which they are defined, such as the local scope for local variables. Because of this, their names can be repeated in other areas without causing any conflicts, which removes one more potential source of mistakes. It is necessary to declare the variables in this way if it is intended that they have global scope. In order to get the settings just perfect, a starting value can be given to each parameter during both the start process and the cold restart.[72]
- **Configurations, Resources and Tasks-** At the top level, the whole system required to solve a certain control problem can be expressed as a Configuration, which includes the

hardware configuration, then memory addresses for I/O channels, and finally system capabilities. Within a configuration, many Resources can be defined. A resource can be viewed as a processing facility capable of executing IEC applications. Within a resource, it is possible to define one or more Tasks. The execution of a collection of programs and/or function blocks is governed by tasks. These can be executed either periodically or in response to a given trigger, such as the alteration of a variable. Programs are composed of a variety of software components written in any of the IEC-defined languages. Typically, a program includes of a network of data-exchanging Functions (such as ADD (ition), SINus, and COSinus) as well as Function Blocks. Contains a datastructure and an algorithm.[72]

Function Blocks include both data and the algorithm, allowing them to track the past. They have hidden internals and well-defined interfaces, similar to an integrated circuit or black box. In this manner, they clearly distinguish between different degrees of programmers and maintenance personnel. A PID temperature control loop is a great illustration of a Function Block. Once defined, the variable can be used repeatedly in the same application, other programs, and even separate projects. This renders them extremely reusable. Function Blocks can be written in any of the IEC languages, and in the majority of cases also in "C" or C++. In this manner, the user can specify them.[72]

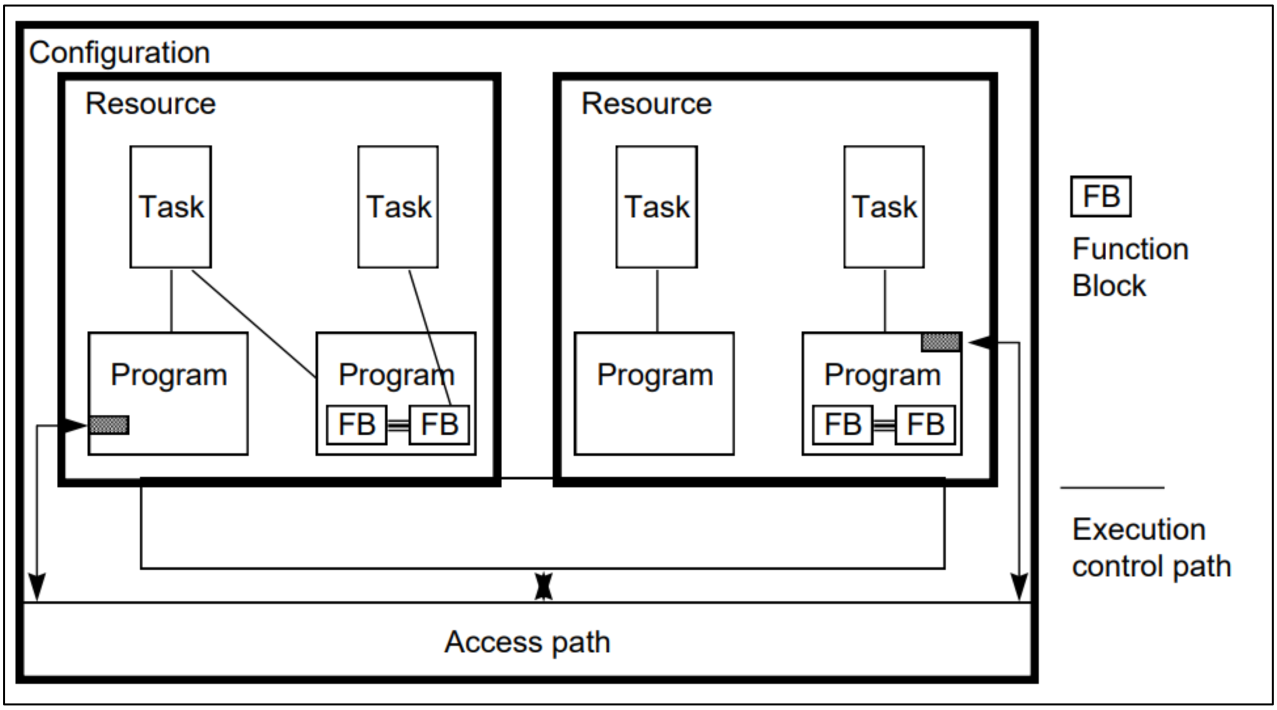


Figure 32: Software model describing Configuration, Resources and Tasks[72]

A typical PLC is comprised of one resource, which is responsible for one task, which controls one program, and which operates in a continuous loop. IEC 61131-3 adds a significance to this by making it open to the possibilities of the future. A prospective era that already makes use of multi-processing and event-driven software. It is not necessary to acquire any extra programming languages in order to use IEC 61131-3, which makes it ideal for a wide variety of applications.[72]

1. **Program Organization Units-** In the language of IEC 61131-3 functions, functional blocks, programs are called as Program Organization Units (POU).

   Functions- According to IEC functions are classified into two categories. Standard functions and user defined functions. Standard functions include ADD(ition), SUB(traction), SQRT. User defined functions are the functions which can be used again and again.

   Function Block- These are similar to Integrated Circuits showing a specialized control function. It contains data and algorithms as well. The interface of FB is very well defined which is similar to IC. This makes it easier and clearer separation between programmers and maintenance personnel. Great illustration of FB is temperature control loop. When it is defined once it can be used repeatedly doesn't matter if same program, another program or another project.

Function blocks can be written in various IEC languages, in majority of instance C is used. It means they can be defined by users only. Creation of new FB is also possible if it is following IEC standard.[72]

```
FUNCTION_BLOCK Example

VAR_INPUT:
        X :     BOOL;
        Y :     BOOL;
END_VAR

VAR_OUTPUT
        Z :     BOOL;
END_VAR

      (* statements of functionblock body *)

END_FUNCTION_BLOCK
```

Figure 33: Function Block Interface[72]

In Figure 33 function block interface is shown. In this example it can be observed as there're two input Boolean parameters and one output Boolean parameter. [72]

Programs-It can be said that program is network and combination of functions and function block. And these programs can be written in any standard programming language. [72]

2.4.3.2 Programming Languages

The programming languages are distinguished in five types according to the IEC standards. So, in the programming syntax and semantics are defined. When this knowledge is acquired, there are numerous systems based on these programming languages. The languages in which programming is carried out are defined one by one in 2.2.3.1.

In end note it can be said that there are various chances and possibilities to design any system using programming languages defined by IEC 61161-3. IEC proves its usability in PLC designing as well as in motion control markets, PC.[72]

3 Exploring SCADA Solution "Honeywell Experion"

3.1 Introduction

Honeywell International Inc. is a publicly traded American multinational conglomerate firm that has its headquarters in the city of Charlotte in the state of North Carolina. It principally conducts its operations in the following four markets: the aircraft industry, the building technologies market, the performance materials and technologies (PMT) market, and the safety and productivity solutions market (SPS).[73] Honeywell Inc. provides SCADA solutions named as "Honeywell Experion Elevate" and "Honeywell Experion Elevate". With these systems Honeywell aims to provide cost effective, easily upgradeable solution. In the problem statement one energy industry problem is picked up to comprehensively understand Honeywell Experion solution.

3.2 Problem Statement

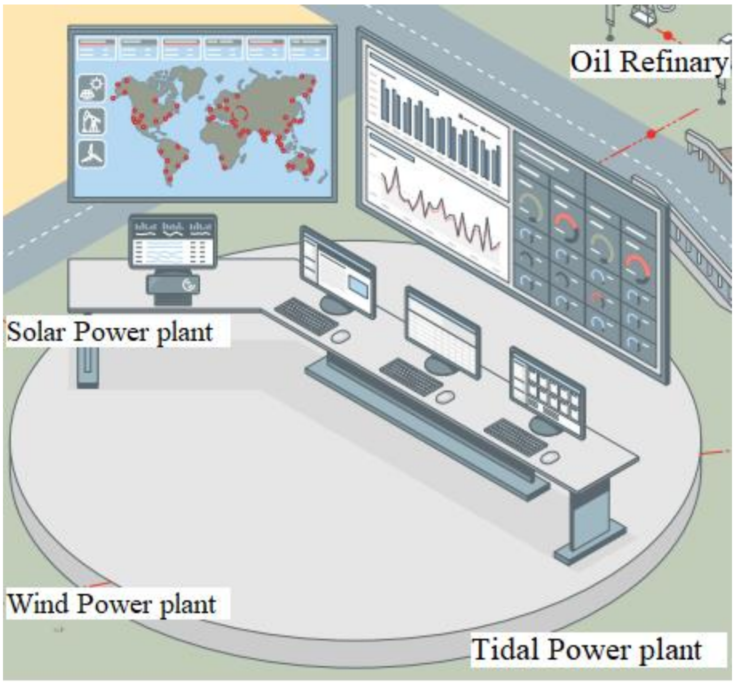


Figure 34: Intelligent, Agile Enterprise[74]

The power plant example is considered for the understanding of the case. Due to high energy demands the natural resources are also used in large extent. There are various energy suppliers in market on which hole energy eco-system is dependent. If there is any trouble in energy generation or supply, it can cause huge loss to economies and can cause shutdown of the whole system. The shutdown then can create chaos. Also, to handle such situations energy companies cannot totally rely on humans. Humans too have limitation and handling such complex energy generation systems is an exhausting task. In this era of industry 4.0 relying on humans is not really an effective way of dealing with problems. Along with previous problems, the energy extraction units are spread remotely, and different locations so control the process and collect the data a quick, reliable, and affordable system is necessary.

Therefore, to address complex processes related issues and to control decentralised energy generation plants centrally one SCADA service provider “Honeywell International Inc.” came up with solution. SCADA solution by Honeywell serves in combined for different application and different locations together and still can be controlled from one place. This concept of Honeywell called as “Connected plant” which has been shown in Figure 34. This solution basically is applied where the connection and monitoring of more than one power generation sites integration is needed. As can been seen in Figure 34 the plants like Solar Power Plant, Wind Power Plant, Tidal Power Plant, Oil Refinery are connected together to one SCADA system. Connected plant uses cloud server to stream the data, advanced analytics. Connected plant is used where the crucial data acquisition and storage is needed for reduction in unnecessary downtimes, underperforming assets, challenges in human capital along with monitoring of data on a centralize remote system. And so, to provide assistance Distributed System Architecture (DSA) comes in action. DSA enables several SCADA servers to function as one within a single asset or throughout the industry, and gives worldwide access to notifications such as alarms, interactive operator messages, and historical data. In addition, Experion SCADA dramatically simplifies the configuration of tens of thousands of assets and boosts operating efficiency with equipment-based templates. Using features like as pan and zoom, task-based filters, and dashboards it reduces configuration by up to 80% and focuses on what is significant.[75]

3.3 Honeywell Experion SCADA Solution

Experion® SCADA is a robust software platform that integrates revolutionary HMI and SCADA technologies. Experion is a comprehensive SCADA solution that offers a scalable, unified, multi-server SCADA system and which has the top level of reliability, safety, as well as security. The Equipment idea from Experion simplifies SCADA configuration and enhances the user experience. [76] It is a cloud-based service which is offering all the functionalities of SCADA system requirement. Whether choosing a standard on-premises solution, an off-premises solution, or if it is a combination of both, Honeywell offers robust alternatives to meet any organization's demands with operational efficiency and simple integration with Experion. Regardless of system size or deployment of regulated or vital data, Honeywell offers alternatives that are both flexible and adaptable.[75] In the description further one specific product of Honeywell called as Honeywell Experion LX is mentioned multiple times for better understanding of the concept. It has been used by mid-tier market industries such as Chemical, Industrial, Food and Beverages, metal industry.

3.4 Core Features of Experion SCADA

User of the Experion doesn't need to start from the scratch but needed just to configure the platform and this is the powerful functionality of the Experion. Once the point and hardware configuration are finished then immediately operations can begin.

- **Operator Interface-** Extensive human factors are considered designing interface of the software.
- **Real-time Database-** Internal systems along with applications, such as operator stations, as well as external applications, simulation have high-speed access to the data stored in the server database. The database is easy to understand thanks to object-oriented technology, and it provides this access to data in a timely manner.
- **Open Connectivity-** The integration of third-party business and information systems is made much easier by the platform's incorporation of open technologies as a basic feature. These technologies provide for read/write access to the database and include Microsoft Excel Data Exchange, Visual Basic scripting, OPC Data Access (OPC DA), OPC Historical Data Access (OPC HDA).

- **On-board history Collection**- Experion Process Knowledge system (PKS) includes an advanced and completely functional built-in historical data. Very long-term storing of historical data is supported. Files from the past can be automatically stored on external media, then recovered and openly accessed when necessary. Using pre-calculated aggregates, the historical data is saved in a highly efficient fashion. All Experion Stations have access to historical data for trend displays, reports, apps, spreadsheets, Open Database Connectivity (ODBC)-compliant databases, and OPC HDA Clients. Even if a trend duration is months or years, retrieval and display of data is nearly immediate.
- **A Versatile Operator Interface**- Flex Station leverages cached SCADA data access. This real-time caching approach is extraordinarily efficient and enables the deployment of a large number of stations on widely spread platforms. Remote Access with Windows Remote Desktop Services enables engineering and troubleshooting from remote sites, especially those with limited bandwidth connections.
- **Scalability**- During the system's lifecycle, the platform may be subject to change if the system requirements shift. Up to 300,000 multiparameter SCADA points along with up to 60 flex stations per server, and an unlimited number of casual connections using eServer are supported. Up to 5,000 RTUs or Controllers can be supported by each server; And the pinnacle of scalability, Experion's DSA, which enables up to sixty Experion SCADA servers to function as a single entity regardless of their physical proximity to one another or their ability to be remotely located from one another, all without the need for duplicate configuration.
- **Reporting**- A large number of built-in reporting tools are available in the Experion SCADA platform, which can be utilized to assist in the documentation or analysis of process and system data and events. Using Microsoft Excel Data Exchange, reporting can be further customized to meet individual needs.
- **Backup Control Center**- The unexpected government regulations, updates in industrial standards pushes control centers to keep readiness for any kind of such incidents while addressing critical infrastructure protection.

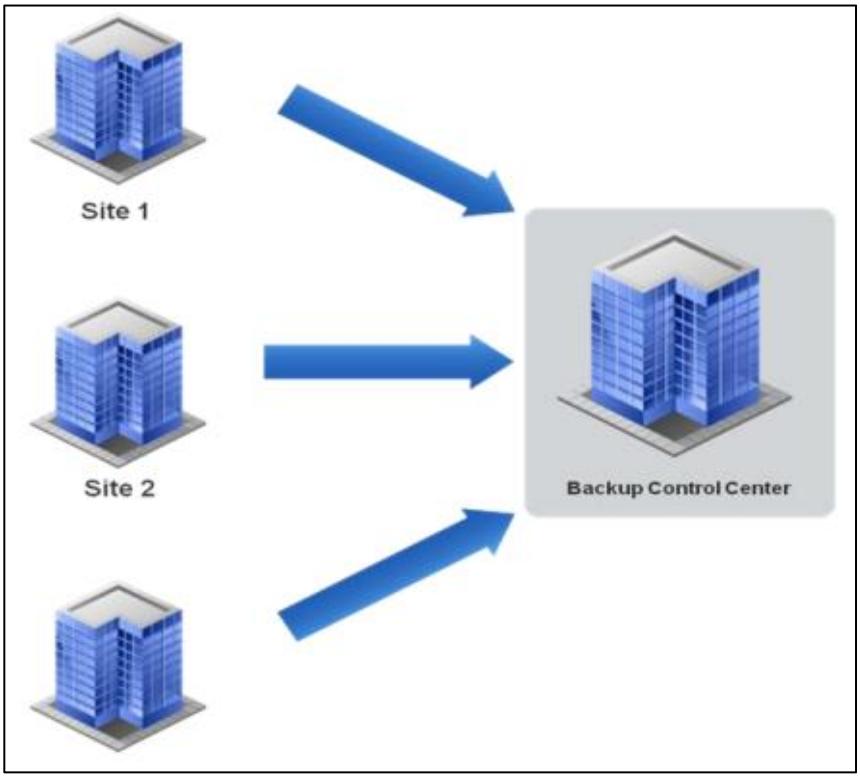


Figure 35: Backup Control Center[76]

The revolutionary Backup Control Center strategy from Honeywell utilizes centralized storage to consolidate all virtual machines in a shared storage environment. The storage is then mirrored across multiple sites. The program for site recovery manager contains all methods for both tests and failovers.[76]

3.5 Components of Honeywell Experion SCADA Solution

The SCADA solution provided by Honeywell in the product name Experion includes all the necessary SCADA components in the system. All of them are explained one by in below subchapters. Out of them the most crucial system component in the Experion product is HMI.

3.5.1 Equipment Display Experion (HMI)

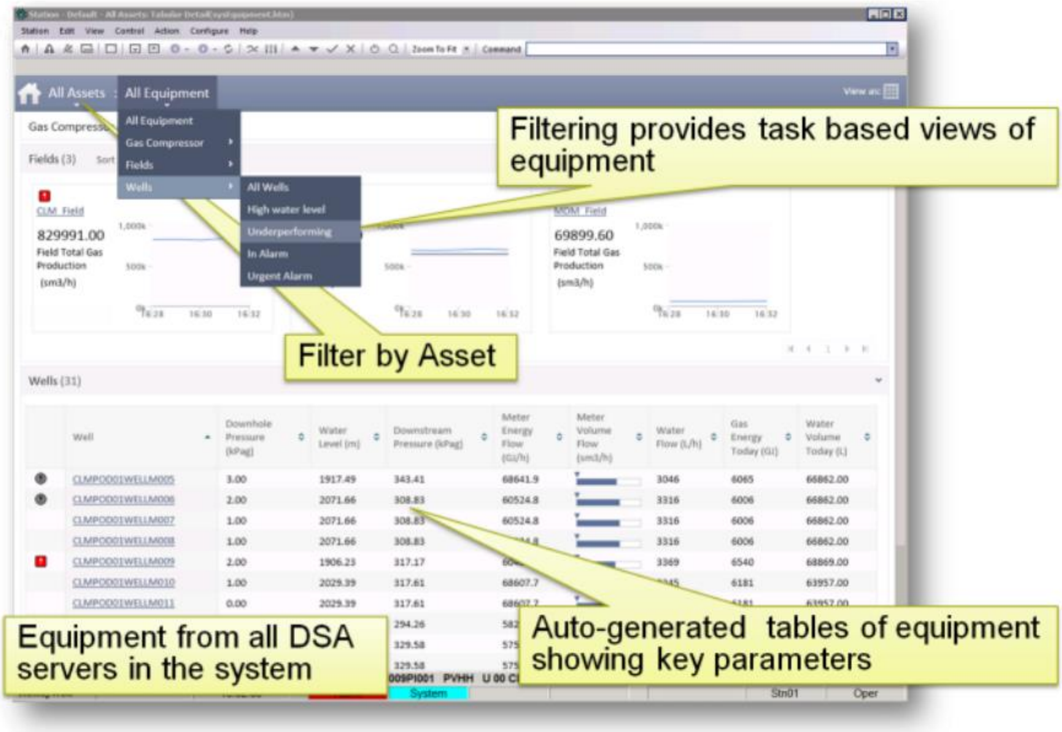


Figure 36: Experion Equipment display[76]

Experion equipment display represents an HMI if compared to the original SCADA system components. This display is equipment configured and it is being driven with the help of information in customised equipment templates. Features of this display includes[76]:

- Only if Task based view needs to be monitored that can be made possible with filters
- In addition to task Assets can be filtered
- All the DSA servers and equipment that the operator uses are covered in the HMI
- The tables are auto generated which shows the key parameters
- The HMI exists banners displaying KPI's as well as status of individual alarms

3.5.1.1 Equipment Templating for Easier SCADA Configuration

Experion users can easily configure the functional block for customized purpose using templating feature of Experion. Experion enables users to design individualized function block templates shown in Figure 37. Additionally, the system features hierarchical building functions that assist users in arranging control modules in accordance with the process hierarchy.[77] The templates are configured according to the individual equipment in the system. Experion Equipment templates are more extensive than conventional techniques since they include all SCADA configurations associated with a certain equipment type. It includes templates shown in Figure 37 such as SCADA points, Algorithm for calculations, Display elements, Communication setting etc. For example, rather than making hundred points and displays a compressor or a pump can be created by defining some unique fields if equipment type is considered. Along with points and display building the equipment template an additional feature can be used. If the equipment templates are standardized those can be applied to multiple plants. The most recent task definitions, trends, displays, etc. can easily be added to these templates.[76]

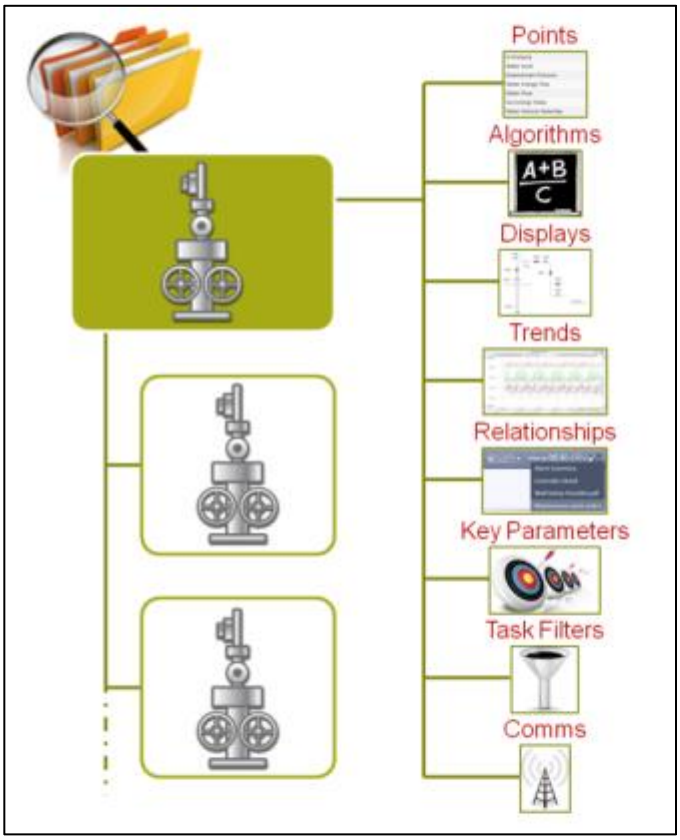


Figure 37: Experion equipment templates[76]

3.5.1.2 Intuitive Configuration Environment in Experion

In the single ordered location, all the configuration tools can be accesses and this is the speciality of the Experion Intuitive configuration environment. Instead of exposing configuration tools to the user, Configuration Studio Figure 38 presents configuration activities as tasks. E.g., “Build SCADA Points”, “Configure Equipment Templates”. While the Experion system is operational, it is possible to make adjustments to the setup. The Experion SCADA server is used to store all of the configuration data, and it does so in a way that takes advantage of its redundancy capabilities, which results in greater resilience.

Configuration Studio incorporates the HMIWeb Display Builder shown in Figure 39. This is the object-oriented tool used to construct and maintain Experion user displays. It features an object browser for quick navigation and modification, a property window for entering and viewing parameters, and a hierarchical collection of shapes. Shapes can be dragged and dropped to rapidly create new and adjust existing displays.[76]

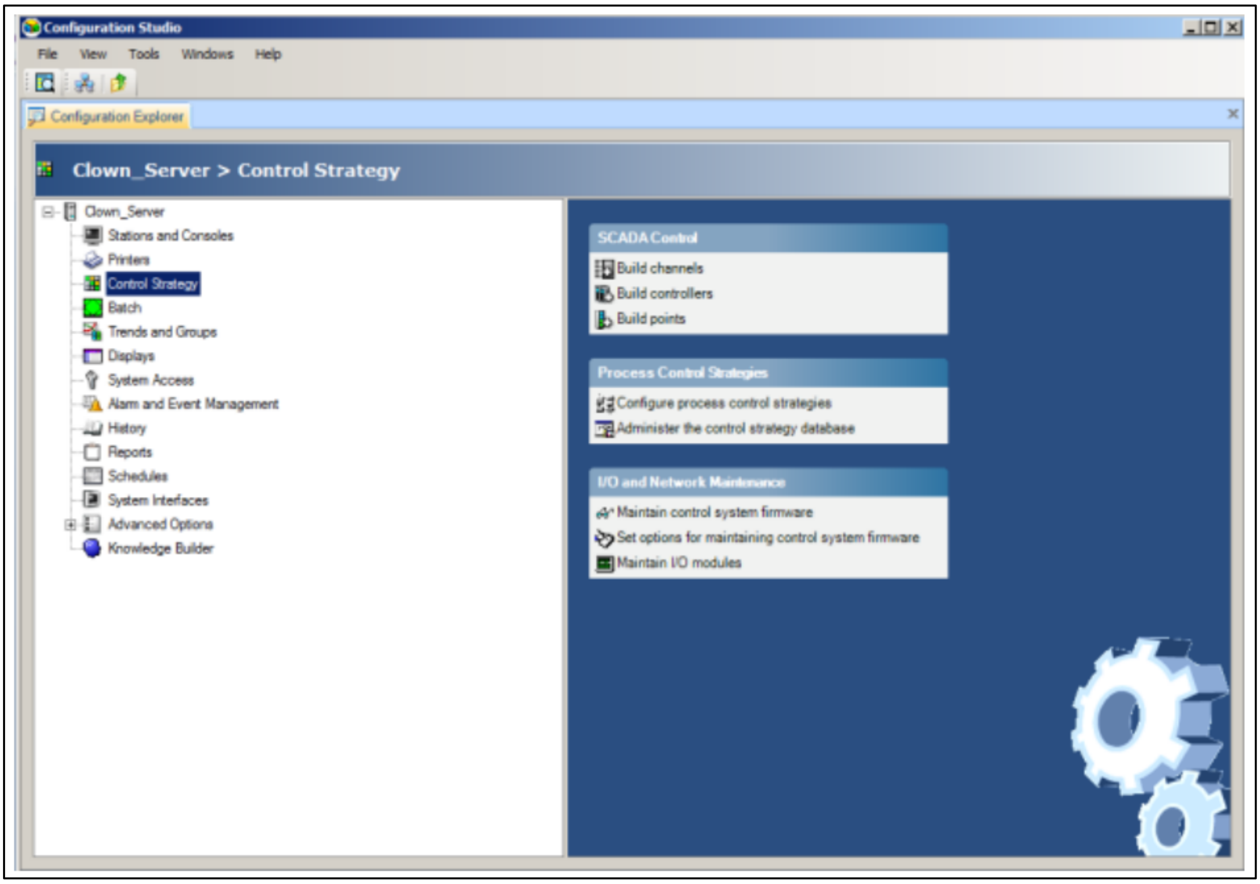


Figure 38: Configuration Studio[76]

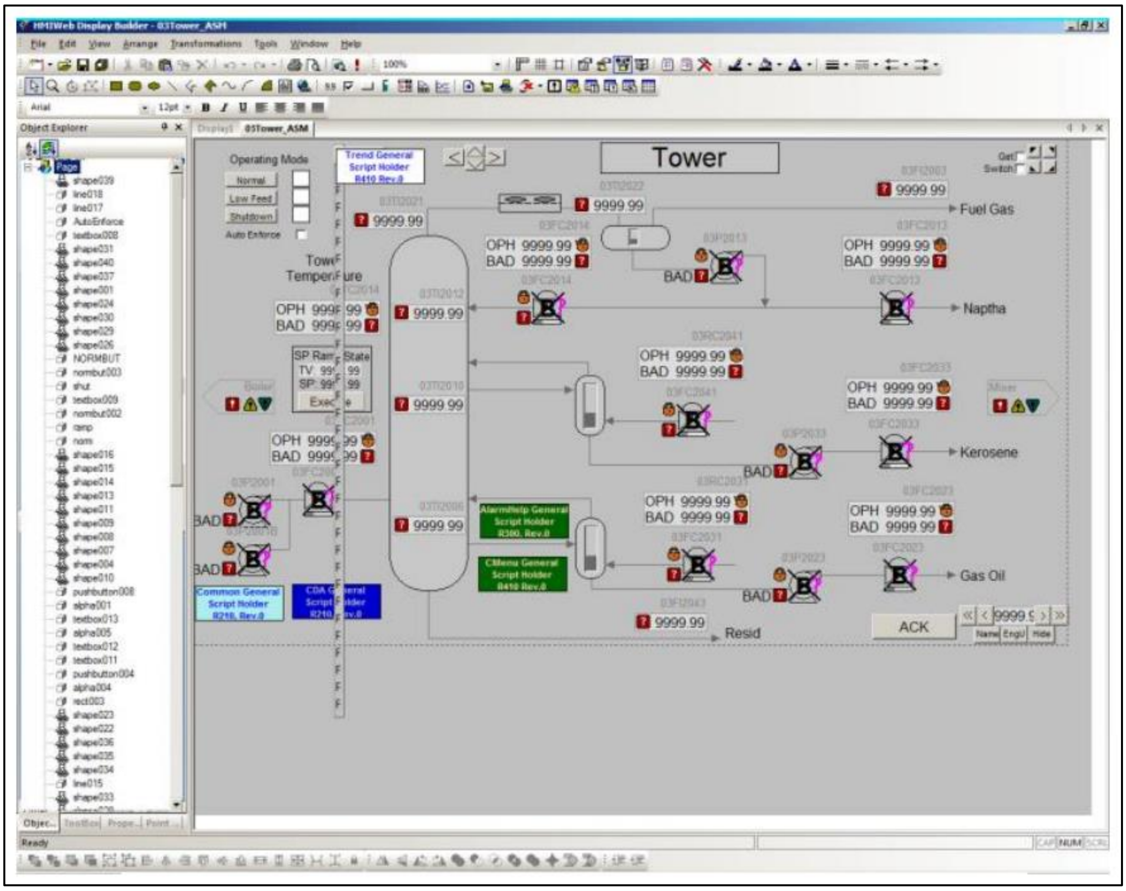


Figure 39: HMIWeb Display Builder[76]

3.5.1.3 Innovative Alarm Management on Display

All the alarms which are being effectively managed is the key quality of alarm management standard as well as it is recommended by practices such as Engineering Equipment and Materials Users Association (EEMUA) Publications 191, International Society of Automation (ISA)-18.2. EEMUA is a non-profit membership organization whose mission is to support the engineering equipment and materials users who are its member companies. Also, ISA 18 is the variant of alarm management standard, and it focuses on basic alarm designing, alarm system monitoring, enhanced and advanced alarm methods and so on. Experion alarm management that is state-of-the-art in terms of efficient alarm workflow, with a fully-integrated and fully-customisable alarm management user interface with a variety of capabilities to filter, sort, and annotate alarms. Also, alarms can be sent by e-mail and SMS to other users.[76]

➢ **Alarm tracker-** The tabular alarm summary has been replaced by Alarm Tracker Figure 40, a next-generation alarm interface that leverages the inherent benefits of to recognize and interpret patterns in order to bring about a step-change improvement. The amount of time required to diagnose and remedy process disturbances is drastically cut down by using Alarm Tracker. Alarm details is another property of alarm notification.[76]

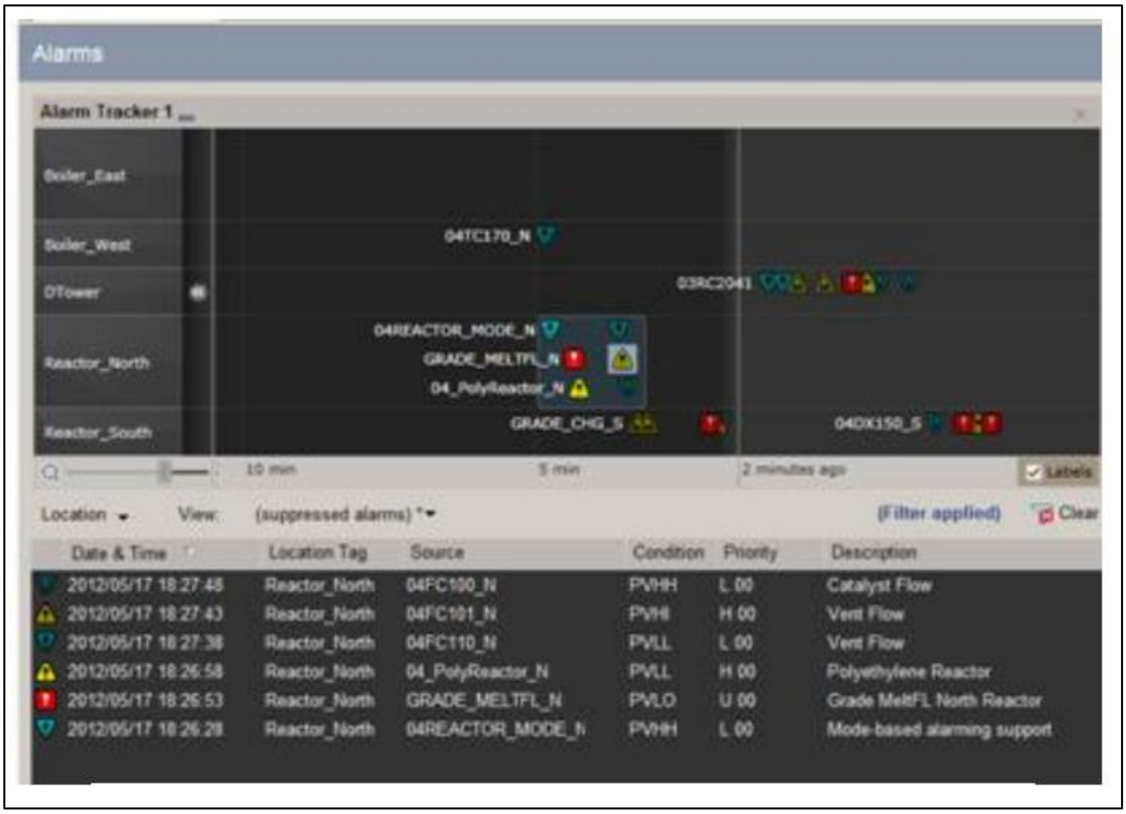


Figure 40: Alarm tracker[76]

➢ **Alarm Details-** This tab (Figure 41) gives information about what has caused the alarm to raise. The justification of the alarm is also displayed in the alarm details with the necessary actions to be taken. If the alarm is being ignored, then what can be the potential impact is also displayed.[76]

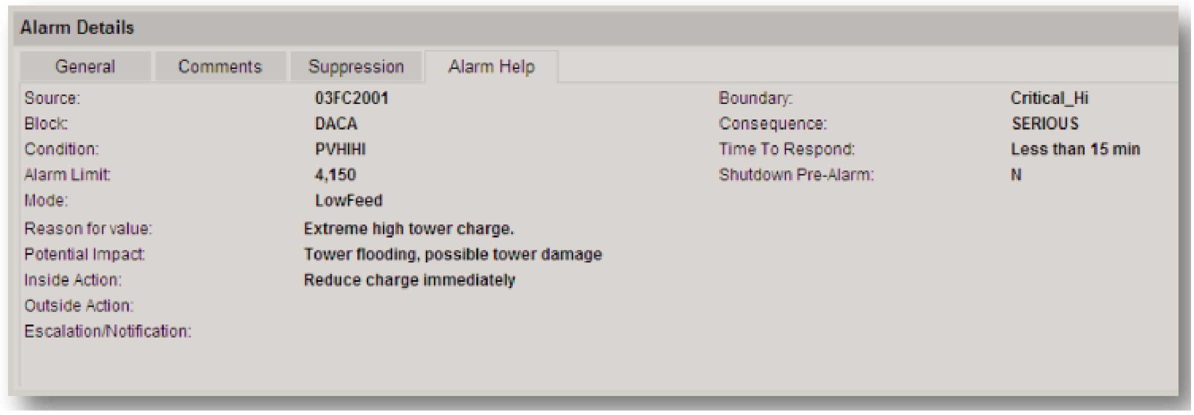


Figure 41: Alarm Details tab in Experion Alarm Summary[76]

- **Alarm Shelving-** With this feature operator can temporarily hide/remove alarm which doesn't require immediate actions and let operator focus on the important activity he is performing.[76]
- **Dynamic Alarm Suppression-** If any rules are pre-configured and that alarm appears then that particular alarm can be suppressed. [76]
- **Alarm Configuration Manager (ACM)** - Honeywell's ACM is an independent product that works in conjunction with Experion but stands on its own. The most important function that ACM can do is that of serving as the master alarm database. It does this by "holding" designed alarm settings along with associated documentation, which may include information about the causes, consequences, and actions taken by the operator. ACM provides a "safety net" by way of auditing and enforcing policies in order to guarantee that any changes made are only temporary and that the engineered alarm configuration is every time re-established. ACM establishes a connection with Experion's Asset Model in order to save varied alarm configurations for a variety of intended modes of operation. In addition, ACM offers solutions that can help work processes for the rationalization and maintenance of alarms.[76]

3.5.2 Honeywell RTU 2020

RTU2020 is a sophisticated, scalable, and flexible process controller that is capable of all remote automation also with control applications. It is designed to interface with any SCADA system, but then when combined with Experion and its drastically reduced SCADA configuration and enhanced operator experience, it meets the most demanding remote automation needs.[78]

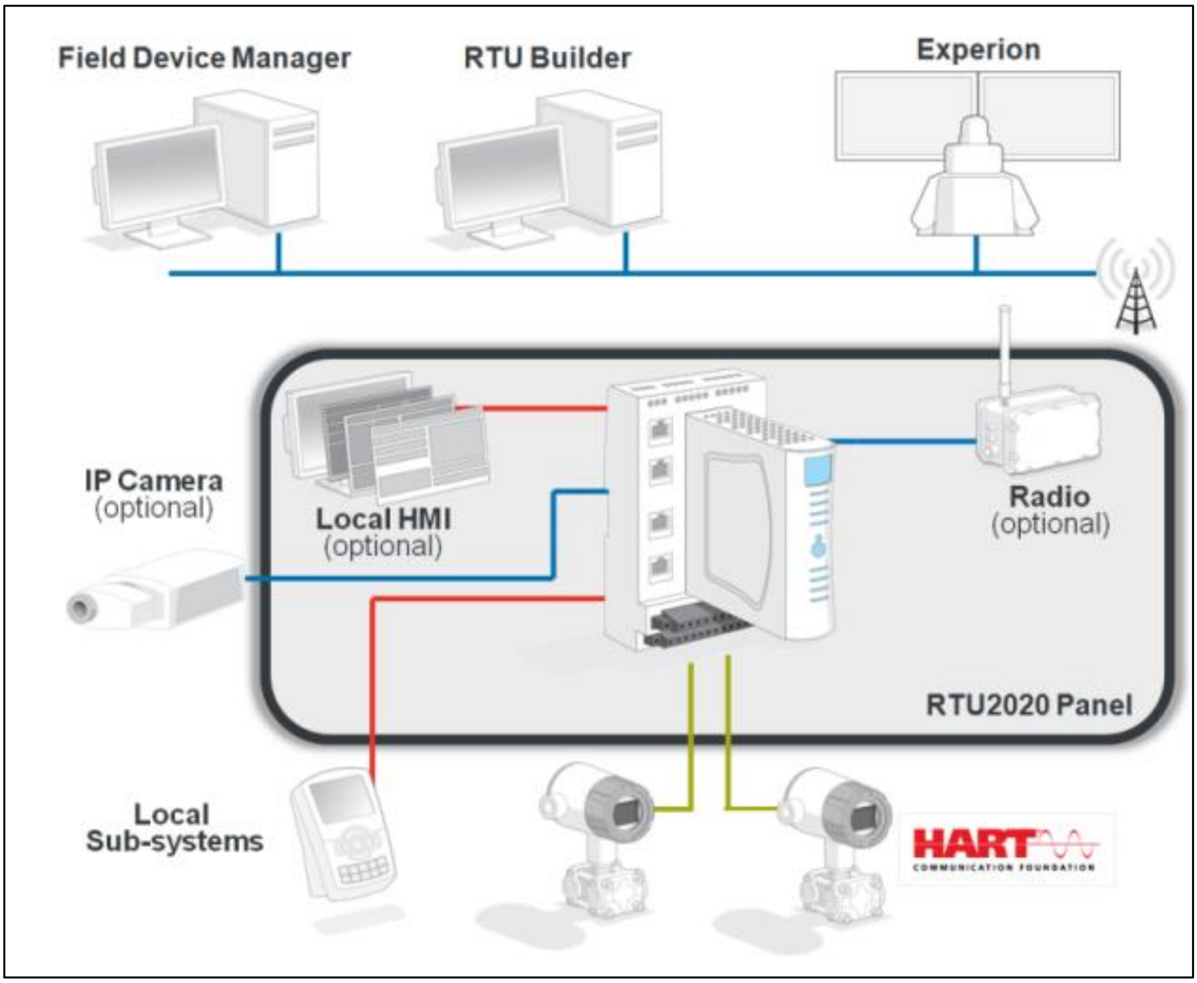


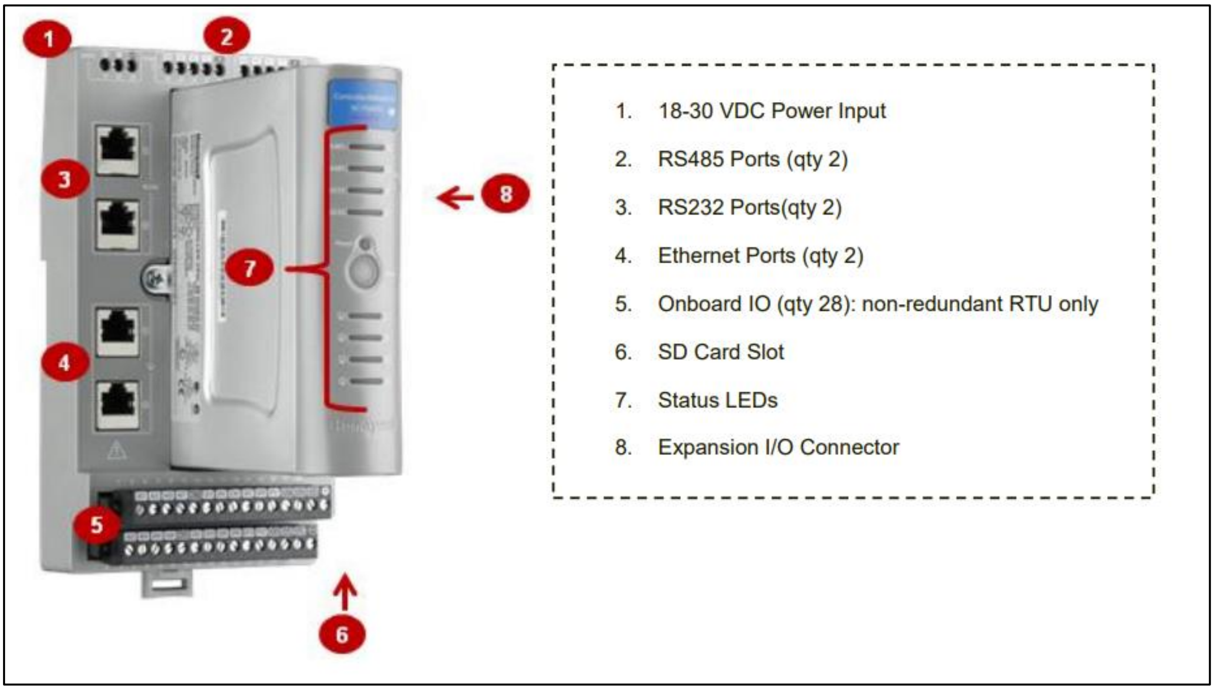
Figure 42: Sample RTU System Architecture[78]

Upstream manufacturing fields necessitate crews of field operators who daily traverse great distances and difficult terrain. RTU2020 can assist in fulfilling this need. It is not only expensive to operate, but also dangerous, and that's just the travel to the location. The combination of the old RTU strength good sub-system interactions with local devices with the more recent functionality of smart device integration with HART enables improved fault modelling, both directly on the RTUs and centrally. IT means that each Field Operator is significantly more productive and can manage several times more sites than before RTU2020 was implemented.[78]

Highway Addressable Remote Transducer Protocol (HART) is a protocol for two-way communication that lets intelligent field instruments and host systems exchange data. And in this case host could be any software application as well as it can be a technician's hand-held device as well as laptop to a plant's process control, safety, or other system which uses any control platform. A pair of HART-enabled devices, usually a smart field device with a control or monitoring system, communicate with each other. Standard termination practices and wiring that is made for instruments make sure that communication works well.[79] Figure 42 demonstrates that RTU2020 has access to both the digitally precise secondary variable as well as diagnostic data of the HART device. After getting an alarm from the RTU, the operator proceeds to a scanned detail page to further diagnose the issue or utilize Honeywell's Field Device Manager to connect over HART IP to the HART device.[80]

3.5.2.1 RTU Instrument Components and Properties

RTU 2020 has a modern and innovative hardware design whose processor module which plugs to the Input Output Termination Assembly (IOTA) which contains devices which are passive those include cable connectors, expansion I/O connector. And these allows expansion I/O modules to make connection without the need of any further infrastructural arrangement. The functionality and features of RTU2020 are one by one explained in the chapter below. [78]



- **Efficient Wiring and Assembly of RTU2020-** Installing built-in terminals can be a difficult and error-prone process. To overcome this, the RTU2020 is equipped with removable field terminals and allowing the installer to wire the terminals while wearing gloves. Additionally, the I/O type and number are printed on the terminals, allowing the installer to positively identify the terminal against the ferrule label. This then saves money on initial installation costs and eliminates wiring errors.[80]

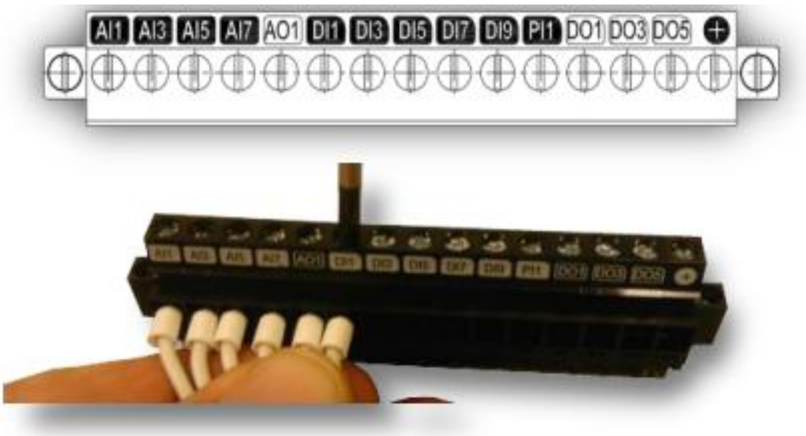


Figure 43: Wiring of RTU2020[80]

In any unavoidable circumstances if there is need of changing RTU on-site, terminal removal saves lot of time as there has been no mass wiring is carried out. It is needed just the terminal strips to unplug and then replacing it with the new RTU. The time taken by RTU, and production backup is almost negligible. [80]

- **Flexible communication ports for RTU2020-** RTU can be distinguished from PLC as it has two features, and those features are its communication capability and with the help of communication history backfill and data logging. RTUs must manage unstable and networks with low bandwidth efficiently. RTU should converse to a remote SCADA system as a slave device. This is usually done over a redundant link with two different types of media. If communications to SCADA are disrupted then the RTU must buffer data. Once communications are restored, SCADA is backfilled with historical data. RTU2020 supports SCADA protocols like Modbus and DNP3 across all scenarios over:
    - Two Ethernet ports
    - Two RS-232 serial ports
    - Two RS-485 serial ports

Obviously with DNP3, the history is backed up to Experion is fundamentally supported. Analog input deadbands of RTU2020 can be adjusted remotely to tune it with the available network bandwidth. [80]

- **RTU2020 Data Logging-** RTU comes with the capability of the data logging which is captured and stored for the purpose of analysis. And this data is then being saved in flash drive or onboard SD card. RTU2020 supports memory card up to 32GB. This can be advantageous to use the same data for future analysis. To retrieve the data logged, RTU builder is used and with it the data can be remotely retrieved and then displayed using windows application. The data can be logged continuously by RTU2020 at pre-defined intervals, or it can be event-triggered. [80]

3.5.3 Communication with FIM4 Fieldbus Integration

Fieldbus is very important for excellent communication of field devices to the software-based control system. Honeywell Experion LX makes provision for effective and strong fieldbus interface using the Fieldbus Interface Module (FIM4). FIM4 has high performing working capacity along with transparent integration with on-field fieldbus instruments into Experion LX. [81]

3.5.3.1 Series 8 FIM4 Kit

IOTA concept is used by All Series 8 interface modules, I/O modules, and the C300, in which the IOTA is mounted to a standard Series 8 mounting channel assembly. This offers all Series 8 modules with a standard cabinet, mounting, power, as well as grounding infrastructure.[81] It can be seen in Figure 44 that FIM4 is being mounted to a FIM4 IOTA. Also it can be observed that redundant kit has two FIM4 modules in contrary Non-redundant kit has one FIM4 module. Additionally, there can be seen many connection points with different purposes. 24V DC supply is provided from Power Control module. It is possible to use third party vendors conditioners. Fault Tolerant Ethernet (FTE) is also marked in figure which is being provide for every FIM4 module. [81]

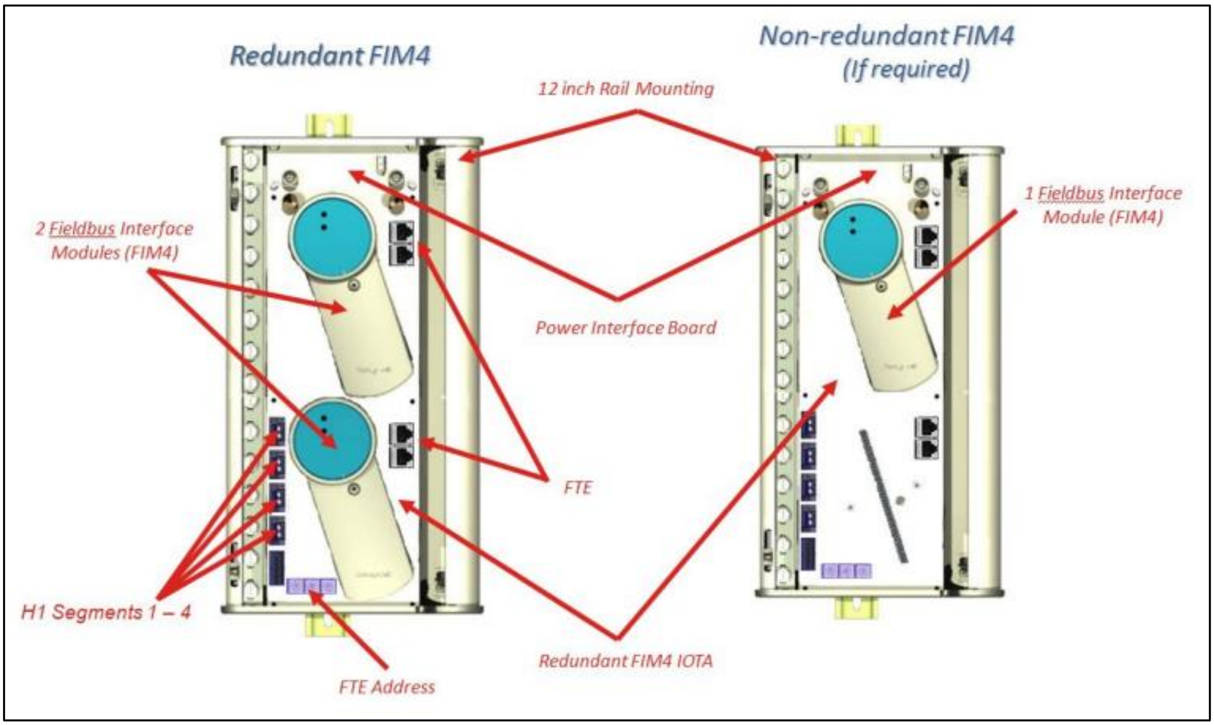


Figure 44: Series 8 FIM4 fieldbus Kit[81]

3.5.3.2 Control Builder for Fieldbus (CB)

Control Builder is the cool graphical engineering tool that comes with the Experion LX platform. It is used for developing and customizing process control strategies, including those that make use of fieldbus. Time saving control builder features considering fieldbus in account are:

- Within CB full device configuration possible
- Commissioning and uncommissioning of the device
- Download of device firmware
- Wizard availability for device replacement
- Possibility of device maintenance with troubleshooting

➢ For operator correct chart information via Chart Visualisation

Chart Visualization is a robust feature that displays information provided by all manufacturers about device blocks and function blocks with directly to the operator. With Chart Visualization, there is no requirement for device-specific customized forms or displays. There it is also not needed to worry about parameter security. Access follows the security level of the Station and has the same settings as all other displays. Minimal technical work and implementation time are necessary. Experion allows for the creation of individualized detail displays. In addition, Experion supports device replacement from operator station itself. A failed or malfunctioning item can be safely replaced with a new or repaired one without requiring engineering assistance. Experion LX R120 and later versions enabling the device vendor to determine where and how parameters are shown and located.[81]

3.5.3.3 Fieldbus Device Manager (FDM)

Experion LX Control Builder and Station delivers all the necessary tools and capabilities for configuring, monitoring, and managing fieldbus devices and related control methods. Users can also identify and address equipment malfunctions. FDM enhances this capacity with additional functions and features centered on FOUNDATION fieldbus devices and asset management coverage. The FDM communicates with fieldbus devices using the FIM. FDM is designed for maintenance users and offers an environment tailored to their requirements. FDM and Experion offer an all-inclusive fieldbus solution.[81]

3.5.3.4 H1 Power Conditioner Basics

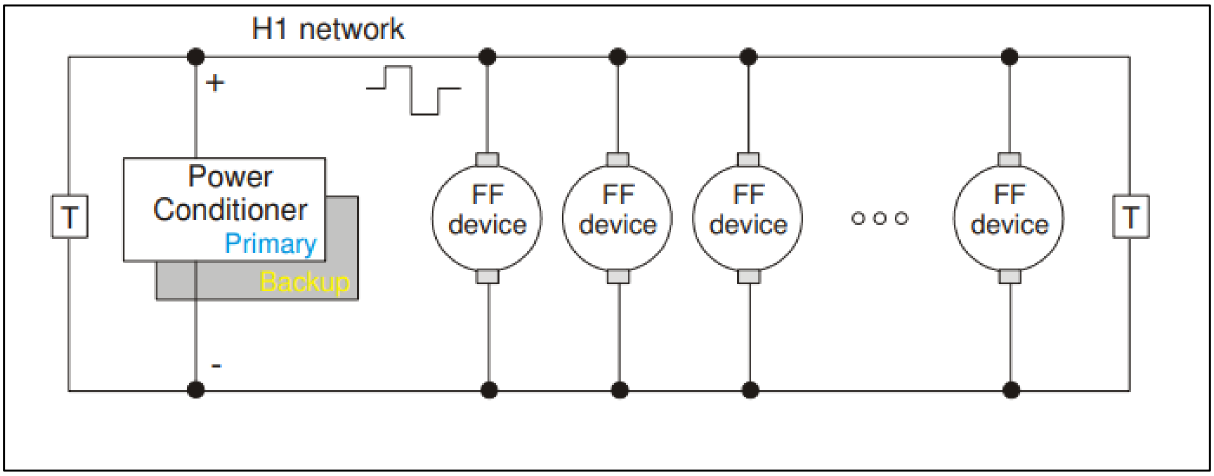


Figure 45: H1 Power Conditioner basic Diagram[81]

Figure 45 is a basic representation of a typical H1 network. All Foundation Fieldbus (FF) devices are simultaneously connected to the network. The power conditioners (non-redundant or redundant) are linked to the network in parallel and provide each Fieldbus device with the 24 VDC to power it requires. [81]

Commonly instrument uses between 10 and 20 mA. The needed size of the power conditioner (in amps) is determined by the number and power consumption of each device. If the terminal is placed at every end it helps in proper communication.[81]

3.5.4 RTU Programming

The integrated configuration environment is the feature of RTU2020 and which is made with RTU Builder. It has been used for configuration, deigning, programming and maintaining RTU investment. Screengrab of RTU builder interface is shown in Figure 46. The point to note is that the RTU builder is fully following IEC 61131-3 protocol and this means it is being supported by all five programming languages. These five languages are ST, LD, FBD, IL, SFC.

RTU Builder includes function blocks designed by Honeywell, which are developed from Honeywell's considerable industry knowledge of market-leading automation controllers. These function blocks are included in addition to the fundamental function blocks that come with an environment compliant with IEC 61131-3. Fan Out, Device Control, Auto Manual, Ratio Control, gas and liquids calculations are some examples of the function blocks that can be found in a controller. In addition, there exist RTU2020-specific function blocks such as the HART Command 3, which reads dynamic variables, and another function block that reads HART Command 48, which gives information about diagnostics status.[80]

RTU Builder is designed so as it can work locally along with working remotely. Time can be saved and the requirement for site works can be reduced by having personnel program either on site or from a remote central location. [78], [80]

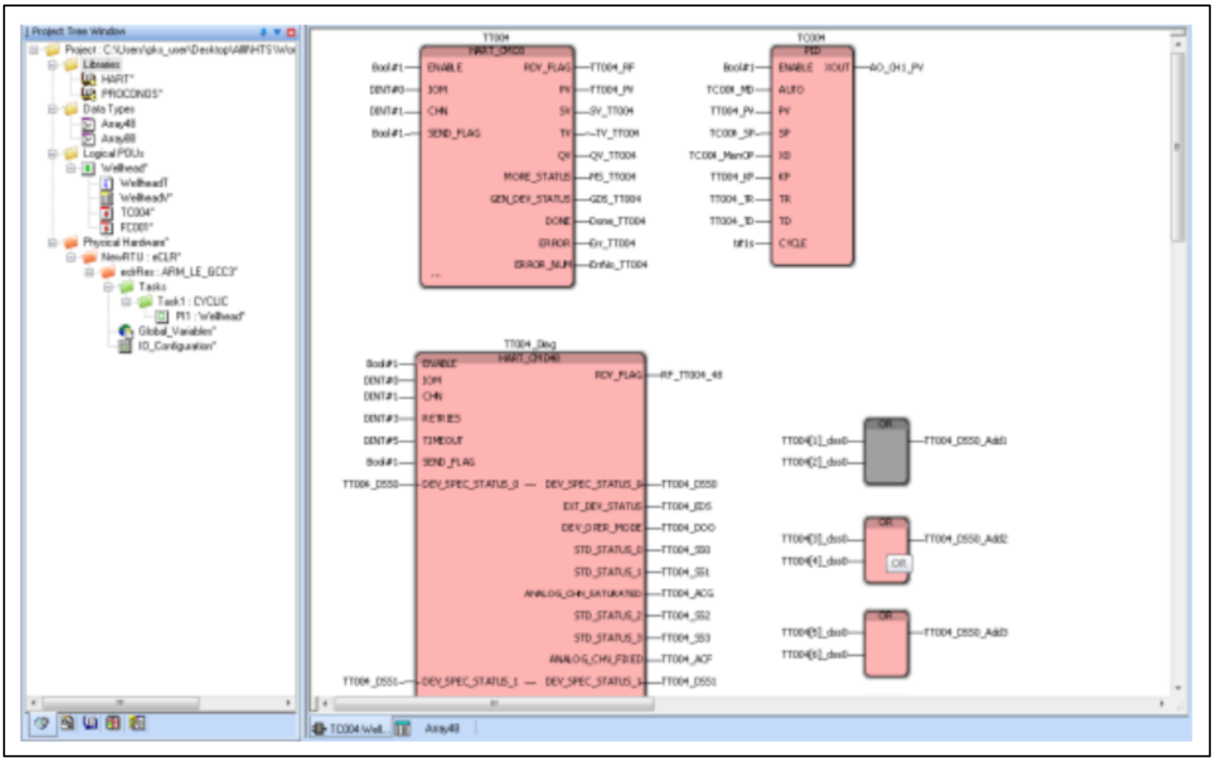


Figure 46: RTU Builder, an IEC 61131-3 Environment[80]

Despite of being distributed at various locations the RTU upgrade can be done remotely. With RTU2020 the health diagnosis of the system can also been done remotely. Hence it can be said that RTU2020 has changed the perspective of dealing with remote working problems.[80]

3.6 Advantages of Honeywell Experion Solution

Honeywell Experion solution has multiple advantages which are summarised in Figure 47.

1. This system can be applied for multiple sites at once and can work without difficulties as it is intelligent and agile in operation.
2. The next advantages include which is like all SCADA systems as it can be operated from anywhere and it is scalable as well as flexible means they can operate various plants at the same time from one place.
3. It doesn't require any personnel on-site for monitoring purpose.
4. The devices are connected assets which makes total system reliable to access.

5. The lower cost of entry allows smaller industries to use the SCADA system helping improve total cost of ownership.

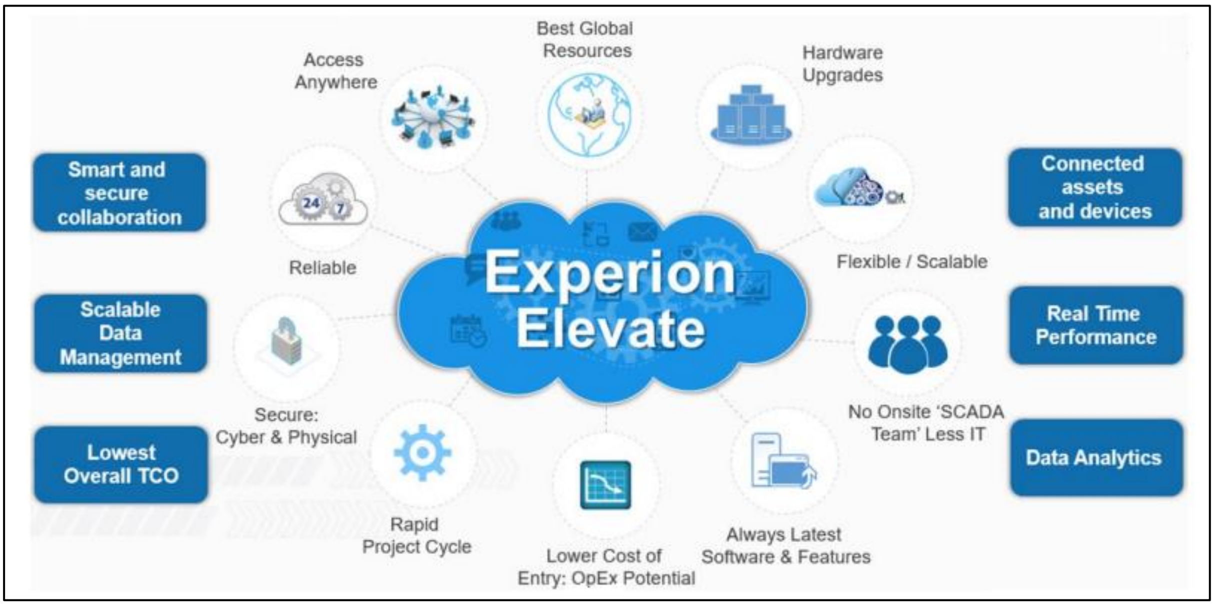


Figure 47: Honeywell Experion Solution[82]

3.6.1 Alternate SCADA Solution Providers

Honeywell is a diverse manufacturing and technology corporation that provides global solutions. The firm works via the automation and instrumentation and services for the oil and gas industries business area. The solution is explained in detailed manner above. [83]

Along with Honeywell, ABB, Schneider electric, GE Grid Solution, Siemens Energy are some of the major suppliers of SCADA system.

ABB provides a variety of solutions for the process and hybrid industries, including integrated automation, electrification, and digital solutions, control technologies, software, and advanced services, as well as capabilities for measurements and analytics, maritime, and turbocharging. ABB produces and distributes a range of products, including PLCs. Schneider Electric offers digital solutions for energy and automation that promote efficiency and sustainability. By putting together energy technologies, real-time automation, software, and services, integrated solutions can be made for homes, buildings, data centers, infrastructure, and businesses. Schneider Electric offers a comprehensive selection of equipment and components for power distribution, energy management, and automation management. GE Grid Solutions offers solutions for the modernization of grid management and the provision of electricity to customers. It develops, designs, produces, and installs an extensive array of integrated hardware and software solutions for energy-intensive sectors, such as oil and gas, telecommunications, etc. Siemens Energy is a multinational enterprise specializing in automation, electrification, and digitalization. Siemens produces fossil fuel power plants and components, smart meters, gas and steam turbines, wind turbines, renewables, solar power plants, geothermal energy systems, hydro power plants, wind power plants, and environmental systems. [83]

4 Experimentation of SCADA System

This section focuses on the real-life case study conducted at ITL TU Graz. The focus of case study is to implement a SCADA solution to a conveyor system.

4.1 System Functionality

A closed loop conveyor system is designed and implemented to carry out movement of different sizes of containers on it. This conveyor runs on an Asynchronous motor. The functions it should carry out are:

- The conveyor should carry containers without break-down.
- The conveyor should function without stoppages.

The more functions to be added after implementation are:

- Necessary sensors data must be collected for monitoring proper functioning of the system.
- Necessary sensor data must be collected to carry out process optimisation.
- Data acquisition for the purpose of generation of historical data.

Figure 48: Conveyor System Used For Experiment

4.2 System Requirement

Any system's productivity depends on a flawless communication system, fault-free programming to monitor tasks, clear interpretation via HMI to the operator, etc. The used conveyor system is also not an exception to not providing any of the above-mentioned features. The system is fitted with different kind of sensors. Basic function which has to be performed by the sensors is to collect data and to use this data to improve general logistic performance as well as improve energy efficiency.

The system must include following specifications:

- Real-time data acquisition and representation from all sensors and input devices
- A device to carry out correct programming to generate correct series of data

- The system should be easy to operate for the people who don't have ample programming expertise.
- The system components should be able to handle different conditions such as vibration resistant or abrasion resistant.

4.3 Components of Test Equipment

To have proper functionality of SCADA system there should be proper integration of different system components. It also depends on how the hardware and software interacts effectively.

Most of the intralogistics applications depends on outputs such as voltage, power, current so in this project also it worked in the same way. In any intralogistics system it is necessary to have proper sensor technology, signal conditioning devices, well-ordered HMI arrangement and in combination with desired controllers for programming and monitoring purpose. If the data acquisition hardware obeys the following criteria, then it helps to create efficient system.

4.3.1 Choosing Right DAQ Hardware

Before arriving at any decision about the selection of DAQ hardware, it is required to address five distinct questions.

- What sorts of signals must one measure or generate?

Different sorts of signals require unique methods for measurement. A sensor (or transducer) is a device that turns a physical phenomenon, such as voltage or current, into a measured electrical output. To generate a physical phenomenon, it is needed to alternatively transmit a measured electrical pulse to the sensor. Therefore, it is essential to comprehend the various forms of signals and their accompanying characteristics. So, based on the signals in the application, it is possible to figure out which DAQ device to use.[84]

- Is signal conditioning necessary?

A common DAQ device for ordinary purposes may measure or create +/-5 V or +/-10 V. Some sensors produce signals that are too difficult or unsafe to monitor directly using this sort of data acquisition equipment. Most sensors require signal conditioning, such as amplification or filtering, before a DAQ device can measure the signal effectively and precisely. Signal conditioning has a significant benefit over DAQ devices alone since it improves the performance and measurement accuracy of DAQ systems.[84]

- How quickly do one need to gather or create signal samples?

One of the most essential characteristics of a DAQ device is its sampling rate, which is the rate at which its ADC samples a signal. Typical sampling speeds are up to 2 MS/s and are either hardware- or software-timed. The sampling rate for desired application is determined by the signal's maximum frequency component that one is attempting to measure or create.

According to the Nyquist Theorem, a signal should be correctly reconstructed by sampling twice the highest frequency component of interest. In actuality, one must sample at least 10 times the maximum frequency to accurately capture the signal's structure. Choosing a DAQ device with a sample rate at least 10 times the signal's frequency guarantees a more accurate measurement or generation of the signal. [85]

- What is the smallest change one must notice in the signal?

The smallest detectable signal change defines the needed resolution of DAQ equipment. Resolution is the number of binary levels that an ADC may utilize to represent a signal. Imagining how a sine wave might be portrayed if it were passed through an ADC with varying resolutions to demonstrate this topic. In Fig: 5 a 3-bit ADC and a 16-bit ADC are compared. A 3-bit ADC may represent eight 2^3 distinct voltage levels. A 16-bit ADC may represent 65,536 2^{16} discrete voltage values. The representation of a sine wave with a 3-bit resolution resembles a step function more than a sine wave, but a 16-bit ADC produces a sine wave with a clean appearance.[85]

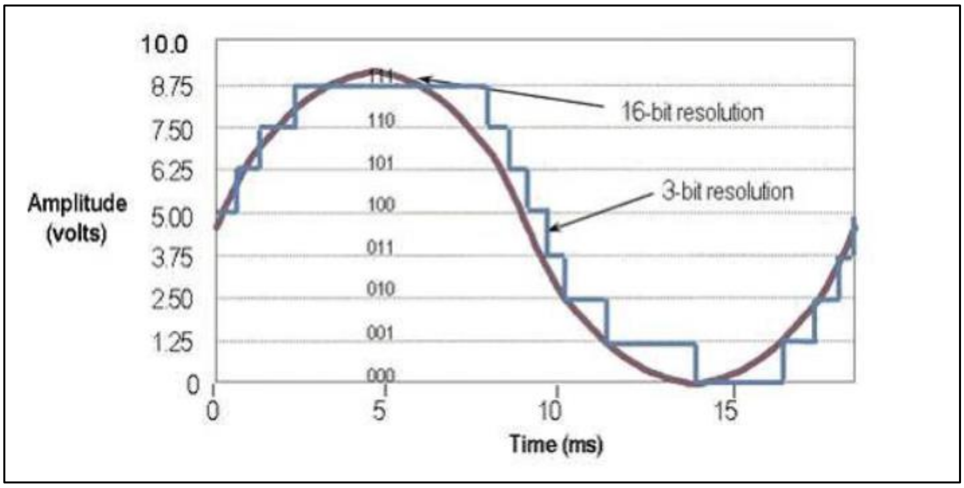


Figure 49: 16 Bit Resolution Versus 3 Bit Resolution Chart of a Sine Wave [85]

- How much measurement inaccuracy is permitted by the application?

The capability of an instrument to faithfully report the value of a measured signal is the definition of accuracy. This concept is unrelated to resolution; yet an instrument's accuracy can never exceed its resolution. Notably, the accuracy of an instrument depends not only on the device itself, but also on the sort of signal being measured. If the signal being measured is noisy, the precision of the measurement is compromised. There is a vast selection of DAQ devices with varied degrees of precision and prices. Self-calibration, isolation, and other circuits may be provided by some devices to increase accuracy. Once you have determined your accuracy requirements, you may select a DAQ device with absolute accuracy that fulfils the application's specifications. [85]

The above-mentioned criteria helped to select proper hardware components for the experimental setup.

4.3.2 Measurement Instrument

Table 2: List of components present in experimental setup [86]

Device	Name/Type	Function
Asynchronous motor	SEW-EURODRIVE WA30 DRE80M4	Provides mechanical power

Tachogenerator	DC tachogenerator/ Speed sensor	Measuring rotational speed-output of the gearbox
Load Cell	Force Transducer S2	Measuring reaction force and converting it into electrical output
Amplifier	KWS3073	Ampifies the electric signal(+/-10DC)
Data acquisition card	NI6221	Translates the signal and sensor data into digital format for the computer
Connector block	NI CB-68LP/CB-68LPR	Connects NI data acquisition card
Personal Computer + Software	LabVIEW	Data visualization and analysis

- **Terminal Block CB68-LPR**

Terminal blocks are modular, insulated blocks used to connect two or more wires. Terminal blocks enhance safety by grounding, isolating, and shielding the circuit's other components. The NI CB-68LPR is an unshielded I/O accessory with 68 screw terminals for connecting signals to NI 68-pin DAQ devices. It has dimension of 167.6 mm × 76.2 mm × 29.2mm. It weighs 162g. It has 68 Screw terminals. It can operate from 0 to 70°C. [87] [88] It then acts as a bridge between sensors and NI data acquisition device PCI 6221 device.

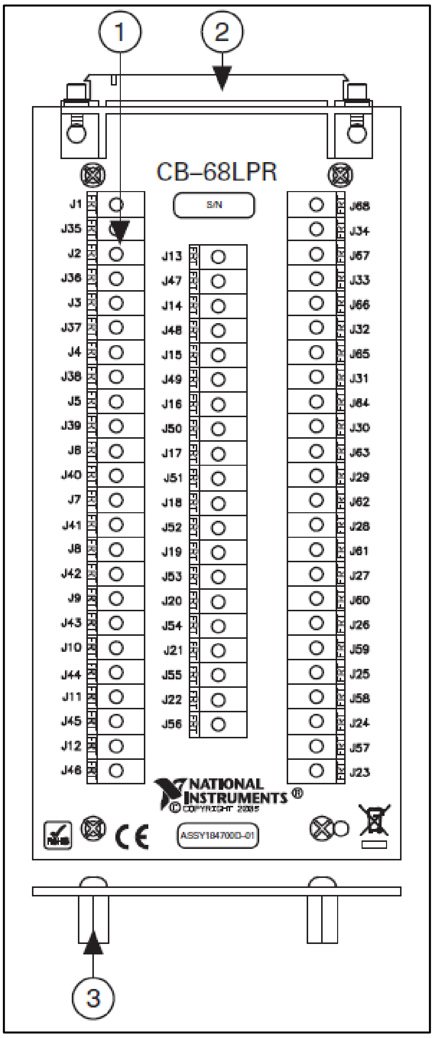


Figure 50: CB-68LPR Parts Locator Diagram[88]

1.Screw terminal 2. 68- Pin I/O connector 3. Metal Standoff Foot

- **NI PCI-6221 Data Acquisition Card**

The PCI-6221 module offers analog I/O, synchronized digital I/O, twin counters/timers with 32-bit resolution, and digital triggering. The module offers cost-effective and reliable data acquisition capabilities for a variety of applications, such as basic laboratory automation, research and development, design validation/testing, and production test applications. Via signal conditioning modules SCC or SCXI It is possible to add functionality for sensing sensors and high voltages to the module. The included NI-DAQmx driver and configuration software simplify the execution and configuration of measurements. There are 16 analog inputs and two analog outputs. There are 24 Digital I/O pins with 16 bit resolution. The input range is from ± 0.2V to ± 10V, while the output range is ±10V. [89], [90]

Figure 51: NI PCI 6221Multifunction Data Acquisition board[91]

4.3.3 Sensing Devices

- **S2 Piezoelectric Force Transducer**

A piezoelectric force transducer, accelerometer alike, produces an output charge or voltage that is proportional to the force applied to the transducer. Unlike an accelerometer, a force transducer's transducing element does not have a connected inertial mass. It must be physically squeezed or stretched in order for the transducing component to provide output.[92] A force transducer is always, in principle, linked to its mechanical environment on both sides of its body. An acting input force results in a tiny elastic deformation of the mechanical structure, which is commonly considered to be proportional to the electrical output signal of the force measurement device. [93] The force transducer is installed on the conveyor in order to measure the force exerted on the belt by the varying container weights. The S2M force transducer can measure both tensile and compressive forces for a wide range of not just static but also dynamic measuring tasks. A strong signal-to-noise ratio is ensured by the signal's constant output level of 2 mV/V. It measures exceedingly accurately even with little forces (the lowest nominal (rated) measurement range is 10 N) and delivers highly accurate findings. In the event of machine damage, the S2M is protected against exceptionally powerful overload thanks to

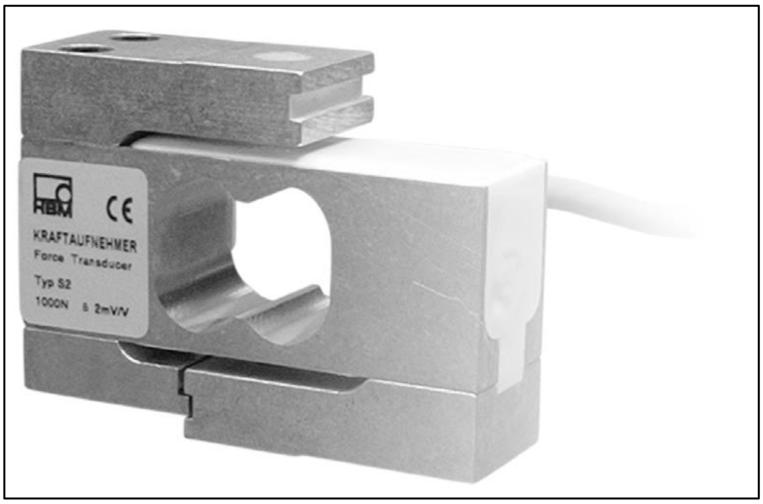


Figure 52: S Shaped force Transducer[94]

its incorporated overload protection. [95] S2 force transducer consists following properties-

- Low temperature dependency of the zero point (200ppm/10K)
- 0.02 percent minimum nonlinearity, relative reversibility error, and lateral force impact
- Overload stop having a force limit of 1000 % the nominal (rated) force
- Compatible with drag-chain PU cable with low force shunt and resistance to a variety of oils and chemicals. [95]

- **DC Tachogenerator KTD 2- .. B14**

The electrical type of tachogenerators known as D.C. Tachogenerators can be used to measure speed. The DC Tachogenerator's armature is maintained in a permanent magnetic field. The machine whose speed has to be monitored is connected to the tachogenerator's armature. The armature of the tachogenerator rotates in the magnetic field as the machine's shaft turns, creating an e that EMF proportional to the muliplication of the flux and speed to be measured.

Electrical data: referenced to 1000 rpm

Type	Rated voltage [V]	Rated current [mA]	max. current [mA]	Load resistance [kOhm]	Amature winding [Ohm]
KTD 2-0,7	7	2,1	40	3,3	60
KTD 2-1 ...	10	1	25	10	85
KTD 2-1,5 ...	15	1	15	15	345

Figure 53: Electrical data for speed sensor[96]

As the permanent field's field is now fixed, the generated EMF is directly proportionate to the speed. The induced EMF is measured using a moving coil voltmeter with a uniform scale that is directly calibrated to speed. In the event of an output short circuit, the series resistance is employed to limit the current. The output voltage polarity specifies the rotational direction. The commutator takes current from the armature conductors and converts internally induced AC EMF to DC (unidirectional) EMF, whilst the brushes gather current from the commutator and make it accessible to the external circuitry of the DC tachogenerator. [97]

Figure 54: Thalheim DC Tachogenerator [98]

The tachogenerator utilized in the experiment is manufactured by Thalheim. It features a high reaction rate, a greater speed range, recognition of rotational orientation, and no power supply.

Its housing which is made up of plastic operates at upper speed limit of 8000rpm. KTD 2-1.5 has rated voltage of 15V and works with maximum current of 15mA.

- **Light Barrier (Photoelectric Sensor)**

Light barrier is also called as Photoelectric sensor. By transmitting light, photoelectric sensors are used to detect the presence of an object. A photoelectric sensor is used to identify an object based on a change in the light receiving level relative to the light emitting level. The photoelectric sensors may emit infrared or visible light. The primary components of a Photoelectric Sensors consist of an Emitter that emits light and a Receiver that receives light. The Receiver receives a varied amount of light when emitted light is interrupted or reflected by the sensing item. This change is detected by the Receiver and converted into an electrical output. [99]

Figure 55: Photoelectric sensor[100]

The photoelectric sensor utilized in the system is of Photoelectric retro-reflective type sensor. The provided voltage varies from 10V DC to 30V DC. It requires 30mA electricity and casing is made up of plastic. Ambient working temperature of this particular light barrier is -40C to 60C. [40] In the current experimental setup 2 nos. of light barriers are used.

5 Solution for Experiment (LabVIEW)

Introduction of the system and specification required in hardware system and the procedure followed helped to create the customized software version based on application purpose. The system is an integration of the Laboratory Virtual Instrument Engineering Workbench (LabVIEW) software with the combination of different hardware variants.

5.1 Solution Supporting Hardware

The conveyor system is fitted with various sensors and a motor to ensure that containers move smoothly on the conveyor. The conveyor system must be monitored to ensure the correct and smooth transportation of loads. Monitoring of data is required for the continued and flawless operation of the conveyor system. Monitoring and keeping records of the data is an issue in conveyor system and here the SCADA solution LabVIEW software comes into application. LabVIEW helps the conveyor system leap one more step in the automation. Firstly, data acquisition is taken place with the use of sensors such as Force transducer, Tachogenerator and two more sensors as light barriers for detection of container. In the solution, after integration with software belt velocity is calculated, Motor torque is calculated, and Load of the container is calculated. Then the acquired data can then be used to identify problems and optimize the conveyor system further. The acquired data includes conveyor belt velocity, torque, force, and detection of the container at the beginning and end of the loop.

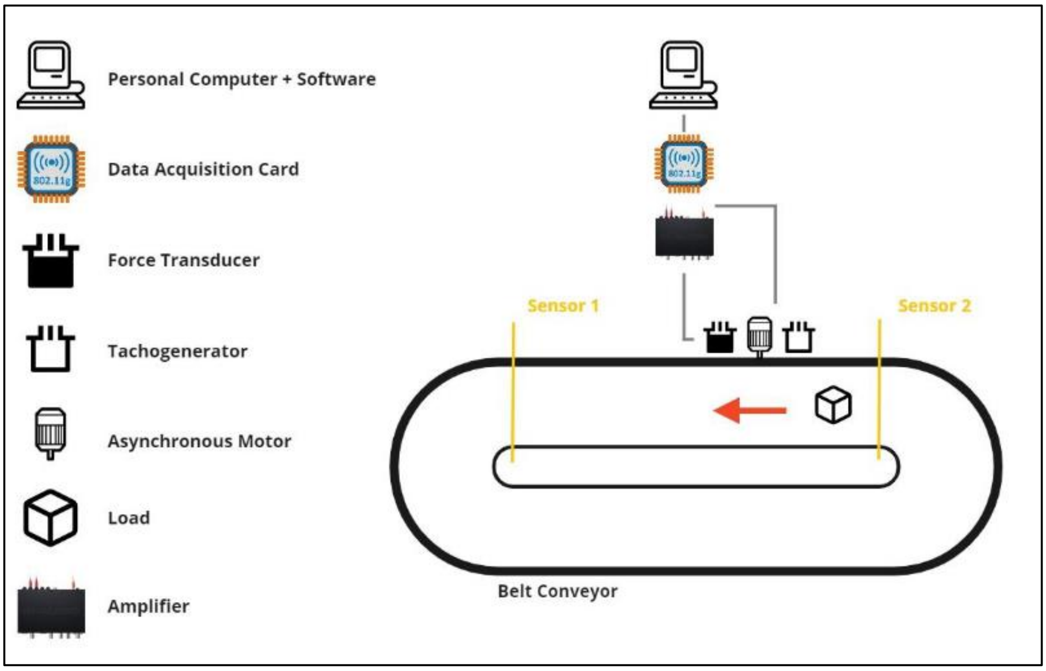


Figure 56: Visualisation of System Components [86]

5.2 Solution Supporting Software

LabVIEW software is the solution for the problem of data acquisition and monitoring. The programming needed for integration of software and hardware is explicitly made possible with LabVIEW.

In industries generally the process control is carried out from remote area instead of setting up control unit near to the actual physical system. Here comes SCADA system in action as this remote data then acquired back using remote terminal unit and processed for further actions. LabVIEW is also a software which collects data then processes it according to the necessity of the user and then stored for historical data compilation. LabVIEW also resembles the list of components present in any standard SCADA system. LabVIEW also includes a computer which serves as an HMI, it has been connected with NI multifunction card for creation of custom automated measurement system.

The history of LabVIEW is uncommon in programming language history because the project's purpose was not to establish a new language. The objective was to create a tool that would let non-programmers such as scientists, engineers, and technicians automate their test and measurement systems. The state of the art had advanced to the point that most instruments, such as voltmeters, function generators, and so on, could be easily attached to computers via standard interfaces, but designing software to operate the instruments in the measuring system remained difficult. LabVIEW-generated applications are known as virtual instruments (VIs). Using the graphical programming language G, VI source code is generated in a window called the block diagram. Input and output interfacing with the VI is accomplished in a separate window known as the front panel and block diagram. The slogan of LabVIEW became "to do for test and measurement what the spreadsheet did for financial analysis." Financial analysts are using spreadsheet programs to rapidly and readily construct custom programme for simulating various "what-if" situations without having to be skilled programmers. Similarly, this technology would allow scientists and engineers to write unique programs rapidly and simply for their test and measurement equipment without the need for programmers' assistance. [34] [101]

The sensors present in hardware gives data such as force, velocity, motor torque signals. The sensors can only provide limited information without application of LabVIEW. And if LabVIEW VI is implemented for the hardware, various formulae can be applied and then variety of results can be acquired. LabVIEW programming segments are explained below which are typically used in creation of the VI.

5.3 Programming the Logic in LabVIEW

The LabVIEW contains two sections one is called s Block Diagram and another one is called as Front Panel. In the block diagram it exists functional pallet library which includes all the mathematical formulae, signal conditioning virtual devices along with several variations which are explained in the subchapters below. Before beginning of Virtual Instrumentation (VI) generation flow diagram of the logic applied is depicted in holistic point of view where basic idea about programming framework can be understood.

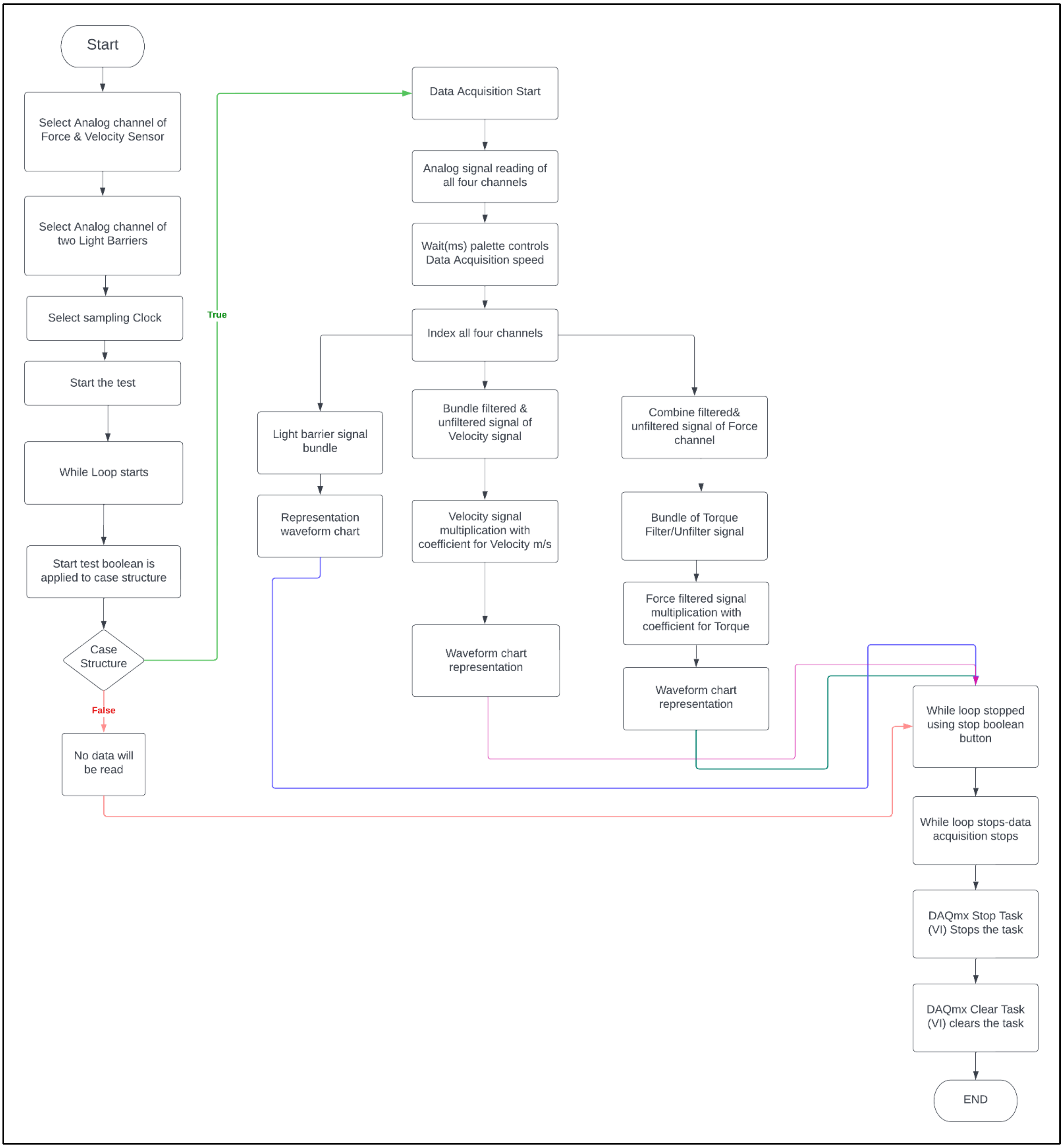


Figure 57: Flow Diagram of Programming Approach Followed

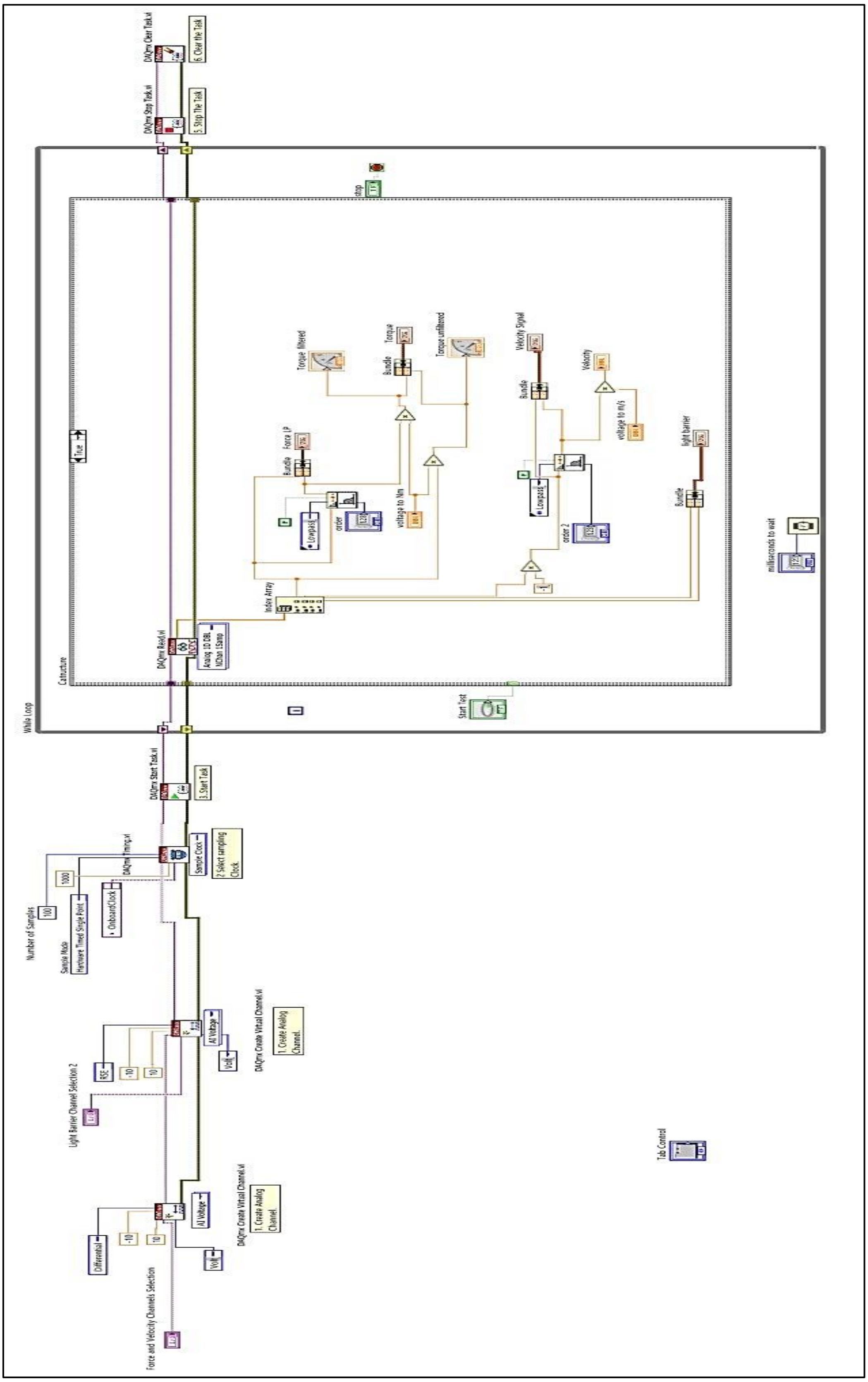


Figure 58: Overview of LabVIEW Block Diagram[102]

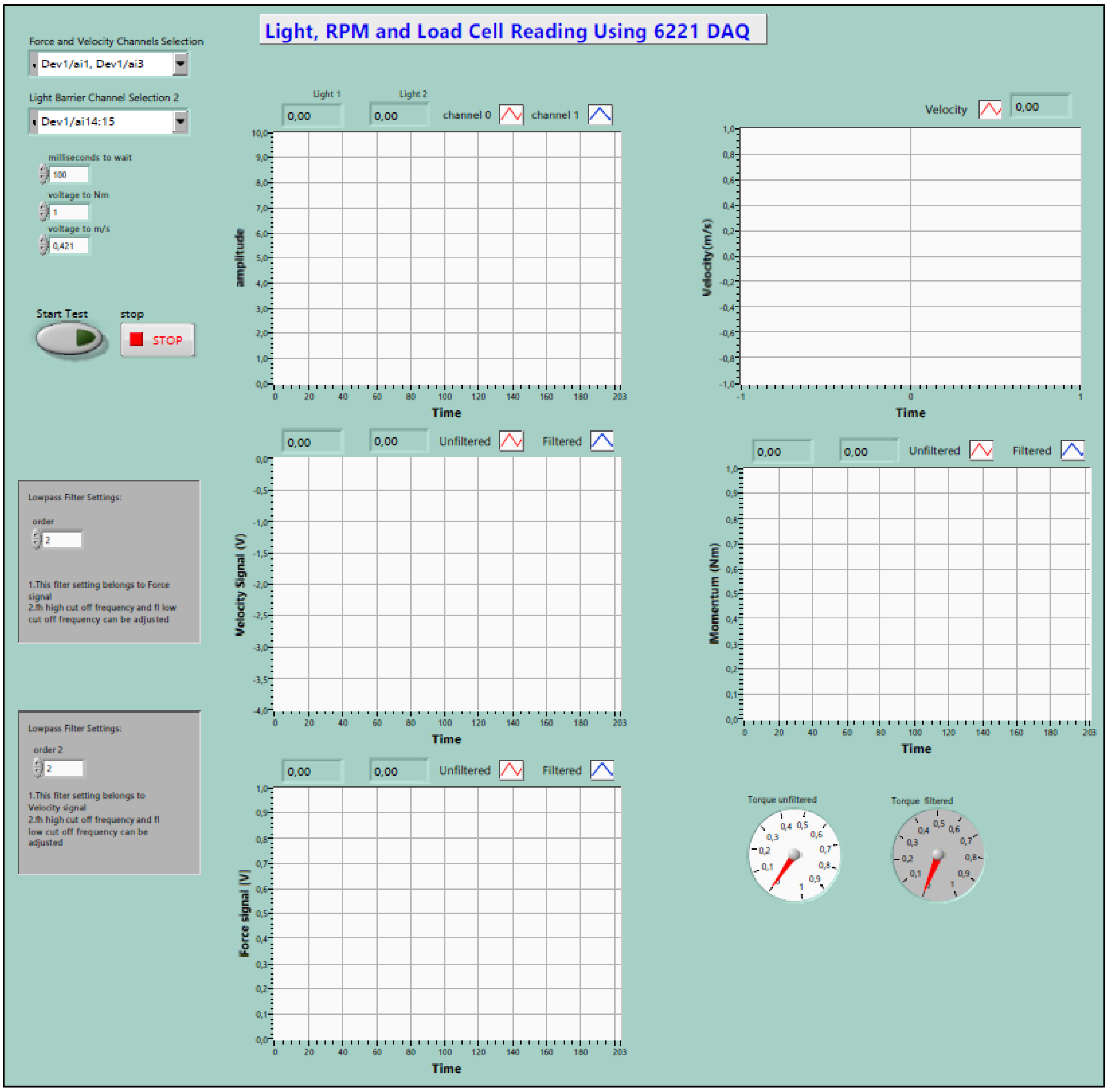


Figure 59: Overview of LabVIEW Front Panel[102]

5.3.1 Configuration of Block Diagram

➢ **DAQmx Create Virtual Channel 1 VI**

Four sensors are present in the hardware so four numbers of virtual connections are provided. Two Light Barriers with same starting attributes are coupled to a single DAQmx channel. Due to the fact that a Force transducer and a Tachogenerator have different starting characteristics than the light barriers, they are connected to the following DAQmx channel. During the initial test phase, a common connection was attempted, but the front panel displayed no results for

Force transducer and Tachogenerator and just light barriers displayed signals. The measurement I/O option from the functional palette is chosen, and then dragged and dropped the "DAQmx Create Virtual Channel" icon onto the block diagram palette.

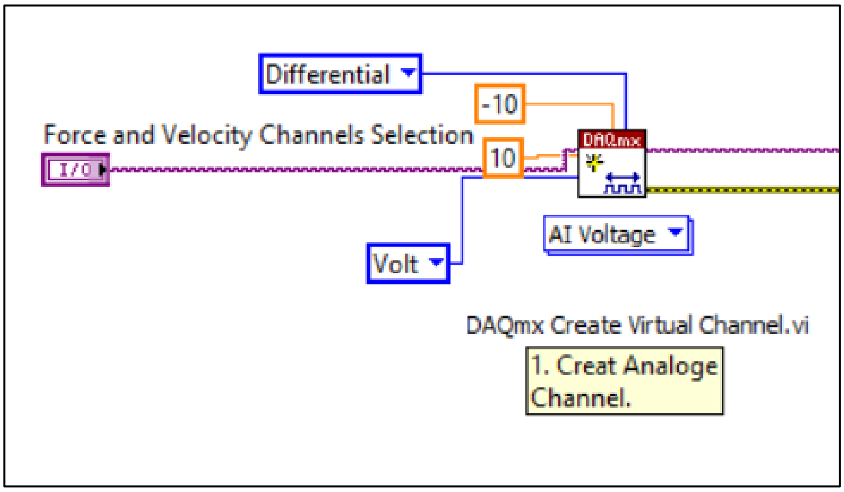


Figure 60: DAQmx create virtual channel 1 (Actual)

The Force and Velocity Channels are only connected to one DAQmx virtual channel as can be seen in the screenshot Figure 60. Also, the meaning of each wire is explained using Figure 61. Orange lines/box in the diagram indicates the highest and lowest operating values of the sensors at which it reads the channels. For Tachogenerator used in the experiment and S2 Force transducer used it has been considered that it reads voltage only in the range of +-10V as per data sheets.[96], [103].

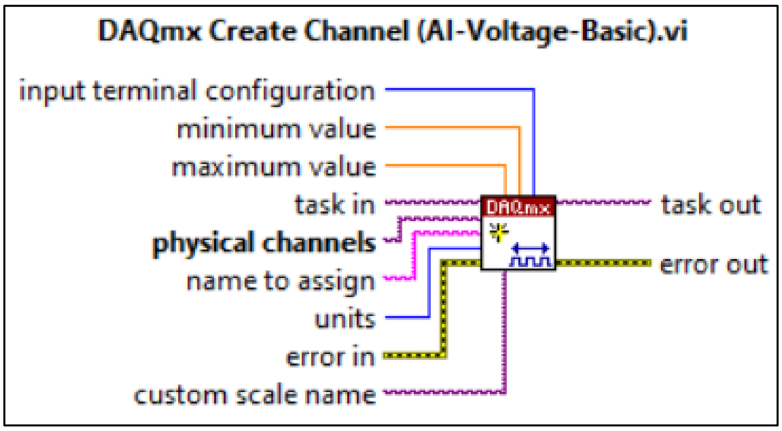


Figure 61: DAQmx create virtual channel user guide

In Input terminal configuration, how the voltage signals are referenced to the ground is designed. The source of the ground signal can be measured using either an NRSE or differential measurement method.[104]In Figure 60 it can be seen as differential measurement system is applied as it is a standard for force and velocity channels. Neither of inputs of this measurement system are tied to a fixed reference as in building ground or earth. Here measurement is done keeping in mind floating ground but the system ground. “Task In” is the region where “Task out” of previous signal is wired for further processing. In “Physical channels” where the actual physical channels are connected. In this case the Force and Velocity channels are connected to Dev1/ai1 and Dev1/ai3 channels respectively as it can be seen in Figure 62. Precise channel configuration is necessary or else the generated graphs can show unscientific results.

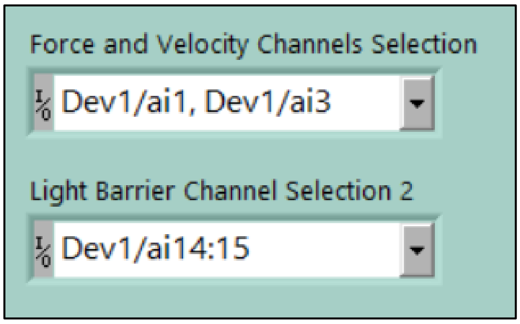


Figure 62: Channel Selection for different sensors

In the “Units” section it has been selected as Volt, as the signal for all the four sensors is received in Voltage format. “Error in” explains error situations that occur before to the execution of this VI or function. By default, there is no error so that is why there is no wiring for the first signals. The yellow dotted line is “Error out”. If an error occurred before to the execution of this VI or function, the error in value is passed to error out. If an error occurs during the execution of this VI or function, the VI or function continues to operate properly but also sets its own error status to error out. [104] The whole conditioned task is then carried forward via “Task out”.

- **DAQmx Create Virtual Channel 2 VI**

The task from first DAQmx channel is then received by second DAQmx channel. The second DAQmx channel is utilized for two light barriers because those sensors have different initial condition than the first two sensors which is represented in Figure 63. The minimum and maximum value of voltage of voltage is set from -10 to +10V for the reference data sheet is being used.[105]

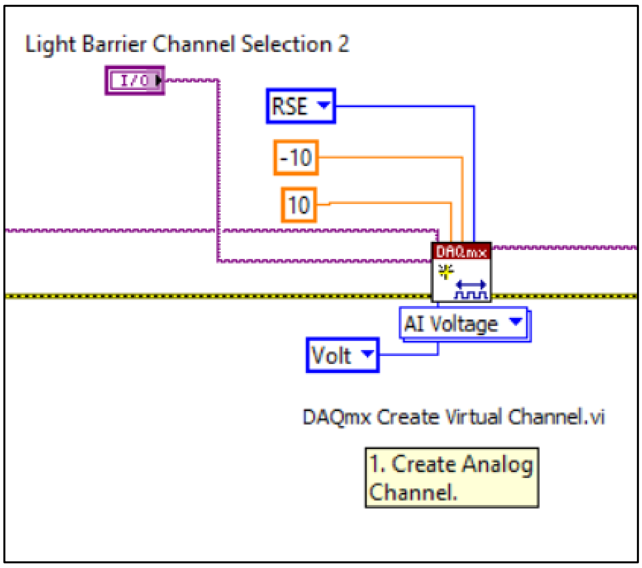


Figure 63: DAQmx create virtual Channel 2

If RSE (Referenced Single Ended Terminal Configuration) method is applied, then results can be noisy sometimes as it takes power-line frequency in the readings. In noise it can be both AC and DC components. Despite this, the RSE measurement technique is applicable when the signal voltage level is high as well as the impedance of the connecting wiring between the source and measurement devices is low. And for the Light barriers RSE is standardized.[104] In second DAQmx module error from first DAQmx module is being carry forwarded. Volt is selected as Light barriers also operates with the Voltage.

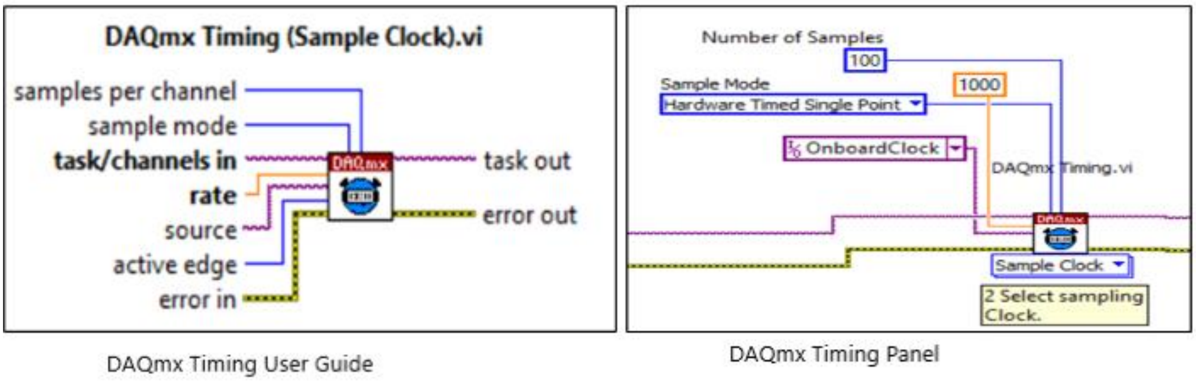


Figure 64: DAQmx Timing Command

➢ DAQmx timing VI

In DAQmx timing rate of the sample clock, per channel samples, number of samples to acquire etc. can be set. The self-explanatory **Error! Reference source not found.** is shown. Error from D AQmx comes to the DAQmx timing. "Hardware Timed Single Point" has been selected as the sampling mode because samples are created continuously utilizing hardware timing and no buffer, it runs until the stop button is pressed. In this context, "Sample clock" is essential. Sample clock is utilized by the device to control the acquisition rate of samples.[104] Time interval between samples time interval is set by sample clock. “Sample rate” is used to specify interval that how quickly the clock generates signal, and it has been kept 1000. 1000 Samples per second rate gives finer representation than 10 Samples per second. Slow sampling rate gives represents poor analog signal. Default “Onboard clock” has been kept unchanged.

➢ DAQmx Start task VI

DAQmx Start task is the function where the wires from previous modules cone along with “Error In”. Here VI goes into running state for further measurement. If this function is avoided, then the measurement will start automatically.

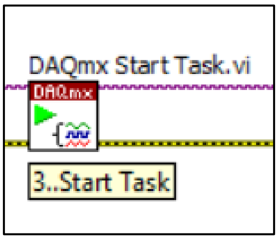


Figure 65: DAQmx start Task

If the DAQmx Start task VI in combination with DAQmx Stop task VI is not used in the program and if the DAQmx read VI and DAQmx write Vi used multiple times directly for ex. If used in the loops, the performance of the application can get hampered.

- **While Loop**

The signal from DAQmx start task VI is transferred via "While Loop" and via Case structure to the DAQmx Read VI. Case structure conditions are set as True or false. If there is false signal or any error in the signal the false condition in case structure will activate. And when the false condition is activated then it will pass out the signals without forwarding it for calculation. When the "While loop" is applied it repeats section of the code. It repeats until certain condition is met. While loop is used because the purpose of reading continuous data has to be fulfilled. The code which is under the grey rectangular border (Sub-Diagram) becomes applicable to the while loop. The while loop is setup with the shift registers. The shift registers are present on the border of while loop box. They are the arrows at left border and at the right border of the loop shown in colour yellow and purple. Shift register is applied basically because it saves data of first iteration and with the reference of first iteration it transfers data for the next iteration. The data from first iteration is passed through the loop and after the calculation the resulted data is transferred back to the start of the loop.

The "i" in the Figure 66 which displays how many numbers of iterations it has been. The loop always starts from 0 for initial iteration. Conditional Terminal, which is red dot, is necessary for specifying whether to execute while loop. The loop keeps on continue until it receives any false value. Therefore, it means True and False conditions can be given at this function.

- **Case structure**

The Case structure is shown in Figure 66. In case structure one or more cases or conditions can be set. To execute which case is determined by value that has been wired to the case selector. The use of the case selector label allows for the determination of which case should serve as the default. "Case selector" decides which case to run based on value of the input data. In current VI, case selector has been attached with the push button and when that switch turned ON from the front panel then only program starts to generate readings. Otherwise, front panel shows blank graphs.

- **DAQmx Read VI**

In "DAQmx Read" VI reads each channel of a single-floating point samples in a task where there are more than one analog input channels. [104] 1 Samp indicates Single floating point sample and NChan indicates each channel in a task. Sample "data" is returned as a one-dimensional array.

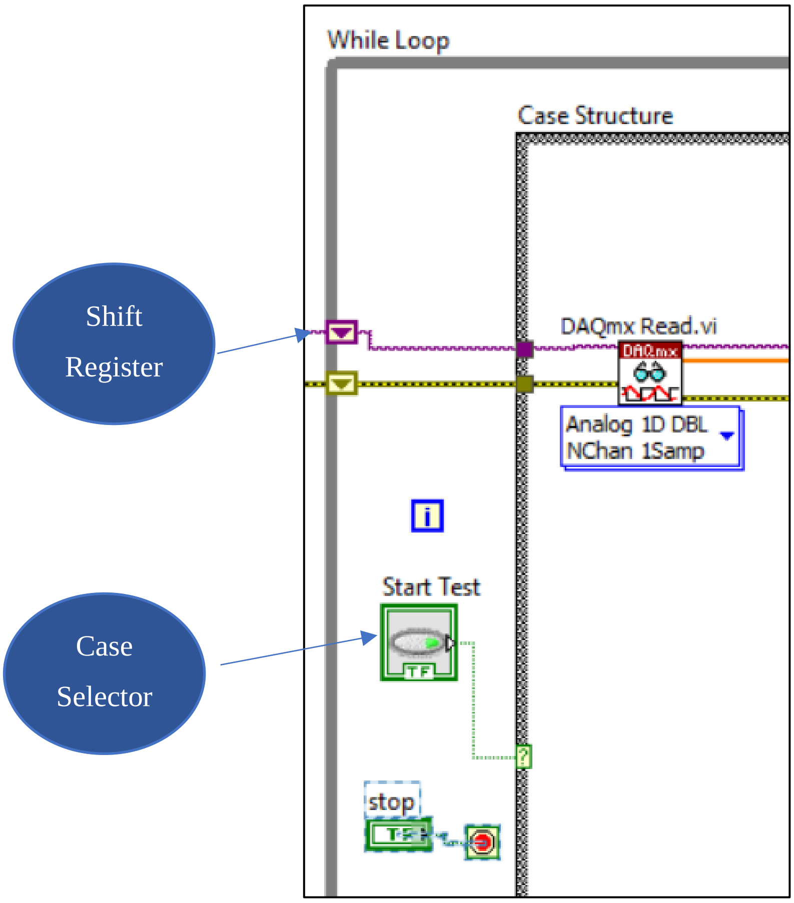


Figure 66: While Loop in VI

To do the function, the array's elements must be treated as individual channels. When using the Channels to Read properties or by manually adding channels to the function, the array will reflect the order in which the channels were added.[104] The thick orange line is indicating carry forwarded data which will be used for formulation.

➢ Index Array

The channels of all 4 sensors are then separated using one polymorphic function named as Index Array which calculates and used to apply formulae for further data generation. The index array is extended to 4 subarrays as in the current VI there are 4 number of sensors which are giving different outputs. Index array returns the default value of the data type defined for the array if the index is less than 0 or higher than the number of dimensions in the array.[106]

➢ Force Signal Logic Conception

As with the Index Array indexing is done then the signals are separated again, and these signals are then distributed again for the specific data generation for specific parameter. In Figure 67 the wiring of Force signal is shown. The first subarray defines force signal. In current task the wire coming from Force transducer gives signal which is used for the calculation of torque along with the calculation of force itself which is exerted on the conveyor system which is

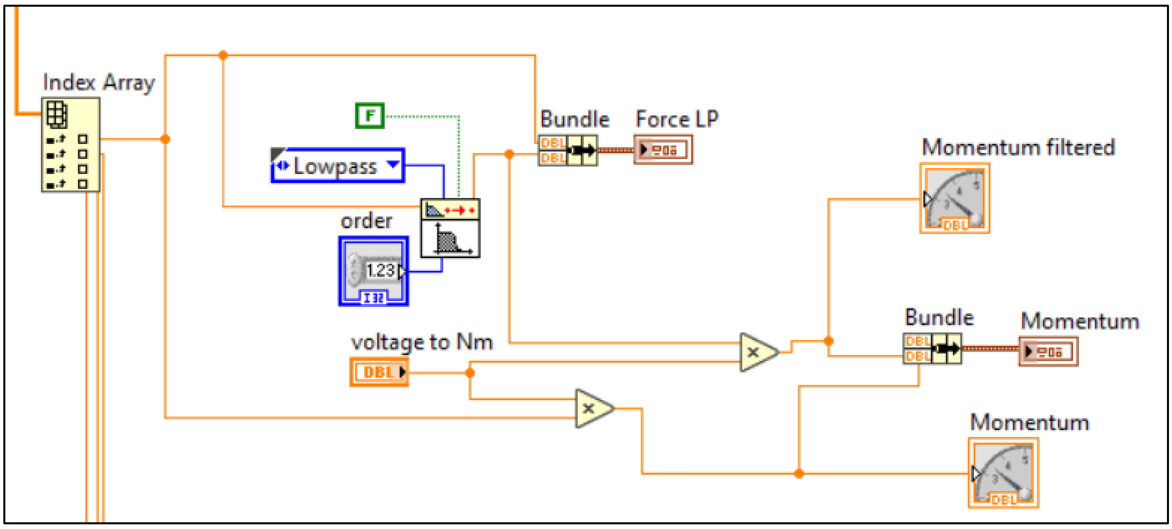


Figure 67:Force signal

because of varying sizes and weights of the container. For the comparison purpose force signal which is filtered and Force signal which is unfiltered both are displayed in the front panel. The comparison suggests why the application of Lowpass Butterworth filter is necessary. Low pass filter is used to reduce the noise impact from the signals as it is explained in the section above. The Butterworth filter exhibits a consistent response over the whole frequency range. Low pass signals omit high frequency signals. And high frequency signals include noise which is unnecessary while calculation of data. In filter as well high cut-off frequency and low cut-off frequency condition can be applied same as in DAQmx Create Virtual Channel but it has been kept empty. Empty meaning it has been kept to the default values which for high cut-off frequency is 0.45 and for low cut-off frequency is 0.125. The order set is 2 which is default and should not be less than 0 or else it returns an error. The low cut-off frequency $f_1$and high cut-off frequency f_2 should follow the following relationship.

$$0 < f_1 < f_2 < 0.5f_s$$

Here f_s means sampling frequency. One signal which is filtered and another one which is unfiltered are then grouped again before “bundle”. “Bundle” is used to assemble the cluster from different elements. The elements grouped in Bundle are displayed in the “Waveform chart”. It is one of the many types of graphs and charts which can be created in LabVIEW. Waveform chart is used because in this case data which is being acquired is in constant incremental/decremental state. Waveform chart displays one or more plots of data. This chart saves history of data which can be used for references and understanding. One option for scale of the chart which can be automatically adjusted is present. The readings can shoot out of the default scale of X and Y axis and to avoid this phenomenon Autoscale X and Autoscale Y options are provided by NI. The data then can be exported too to Excel. It helps in generation of historical data acquisition. The same force signal is represented in one waveform chart in the front panel. The unit for force signal is written V because the signals are generated in the form of voltage.

- **Torque Signal Logic Conception**

The force signal wire is then branched into another signal for the calculation of torque. The unit of torque is Nm, which can be derived from force. The force value is a variable that can be taken directly from the wire. There is a coefficient value wired named "Voltage to Nm", which can be reduced or increased manually on the numerical control in front panel. This value must be calibrated directly on the hardware and the most logical and correct value has to be setup. In the hardware setup, this value of “Voltage to Nm” has been set to 1 after manual calibration. The VI can be used for different setup and this control can be calibrated according to the requirement.

In the process, two distinct calculations are performed for differentiation and comprehension purposes. One is for the filtered signal of the force and torque, while the other is for the unfiltered signal of the force and torque. In addition to waveform charts, gauges are also added for representational purposes in the front panel.

➢ Velocity Signal Logic Conception

Next subarray separated from the index array is "Velocity Signal" which is shown in Figure 68. In here the motivation for separating the array is to calculate the velocity of the conveyor belt. The velocity changes directly proportional with the load being carried. Like force signal here as well the Butterworth Low Pass filter is used. The purpose again is to pass only low frequency signals and omit unwanted noise from the frequency.

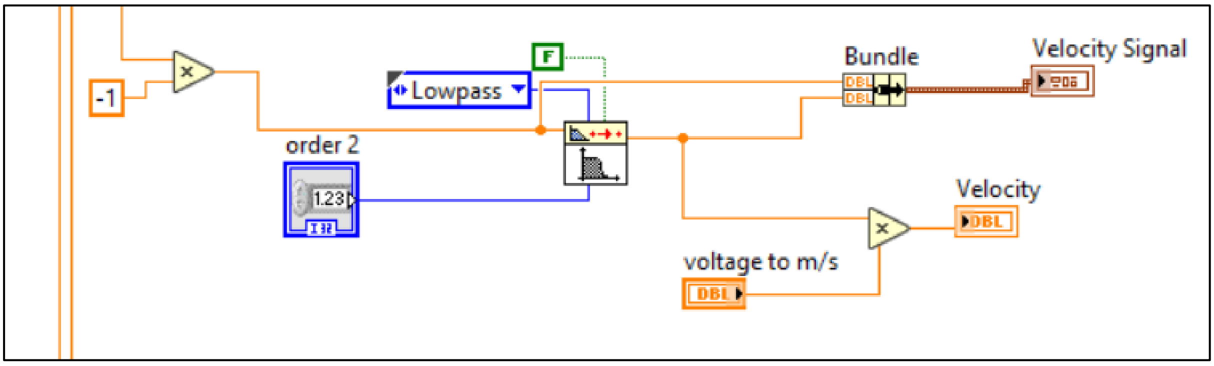


Figure 68: Velocity signal

Firstly, the received voltage is multiplied by -1, and the reason behind is that the voltage received is also negative, so the velocity will be. The signal is then passed combined back again using bundle function. In this step, the filtered and unfiltered signals are recombined into a single signal, which is then displayed as a waveform chart. This signal is then naturally produced in the form of Voltage, which is displayed on the front panel of the VI. The recombination is wholly for the understanding purpose. Another branch of the velocity signal is then multiplied with the coefficient value, and after calibration with the actual hardware, the right coefficient is determined. The value kept is 0.421. If the value is altered in any way, the result will be an inaccurate readout for the velocity calculation. Still there is an option of alteration to use it for different hardware setting. In total 2 graphs are added related to velocity out of them one graph is a combination of filtered and unfiltered velocity voltage and the next one is actual velocity in m/s after implementation of velocity formula with the coefficient.

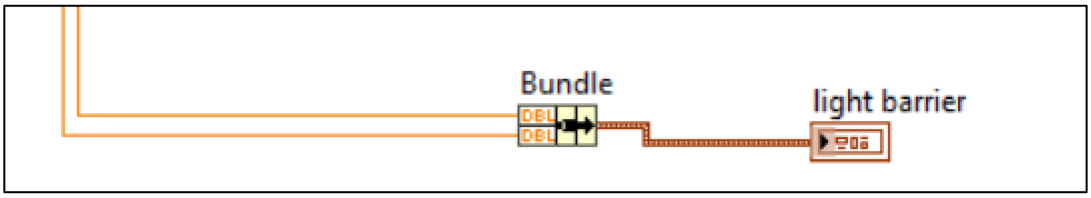


Figure 69: Light Barrier Signal

➢ Light Barrier Signal Logic Conception

The third and fourth wires are depicting Light barriers. The light barriers signal is necessary for identification of the presence of the containers in the loop. The two light barrier signals are then bundled together using Bundle function. The signal is again then showed in waveform chart format. Here ends the main calculation part of the VI for all the four sensors.

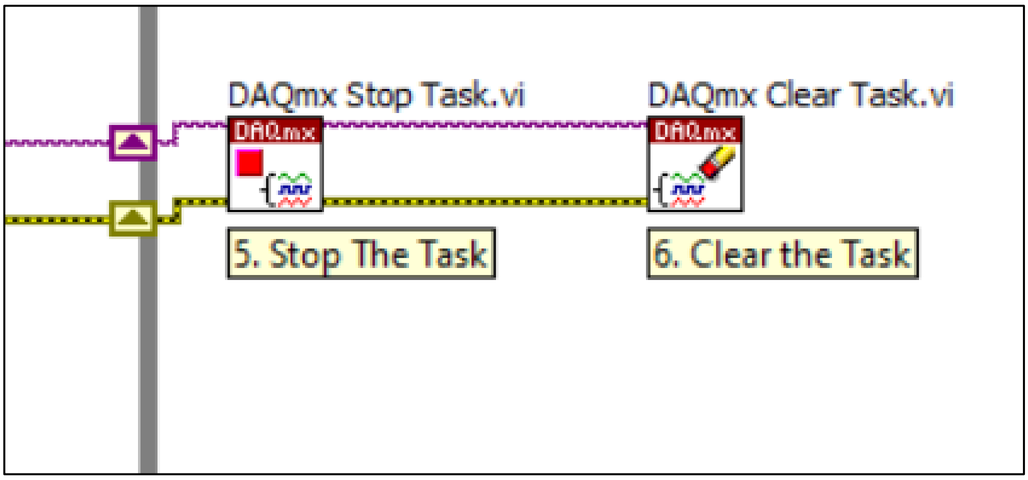


Figure 70: Stop task and Clear task function

➢ DAQmx Stop Task VI and DAQmx Cleat Task VI

The goal of the "DAQmx Stop task" VI is to stop the task, after which the signals are restored to the state they were in prior to the DAQmx Start Task VI. As mentioned earlier, if DAQmx Stop task VI and Start task VI is not used in the VI then it can reduce the performance of the VI. The purple wire is which is Task channel In a one end and Task channel out at the other end. Same principle works for the Error In and Error out. The second VI in the Figure 70 is DAQmx Clear task VI. This VI clears the task. In the case of application of DAQmx create virtual task in the end DAQmx Clear task should be used. If this is not used, then the VI will accumulate unnecessary memory.

➢ Wait (Timing Control)

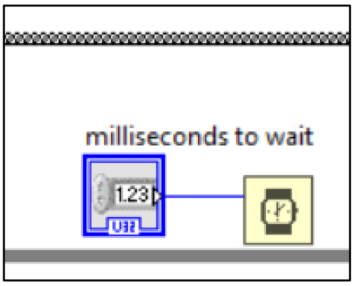


Figure 71: Wait function

Waits the given number of milliseconds and then after returns the millisecond timer's value. The requested wait time may be shorter than the actual wait time by up to 1 millisecond. This function makes asynchronous system calls, yet the diagram's nodes operate synchronously. Therefore, execution of this function does not conclude until the stated time has passed. [104] In the current program the wait value is kept 100 milliseconds. After 100 milliseconds, the next graph point will be generated. If the waiting period is too short, the development of results will be too rapid and the observation will be troublesome.

➢ **Tab Control**

Final step in creation of VI is to create “Tab Control”. There are number of charts present in the current VI and if they are not arranged properly then it can look messy and can create confusion while observing any specific chart. Tab control makes the charts easier to differentiate and so can be used for better understanding. Using this number of pages can be created depending upon what charts when to analyse.

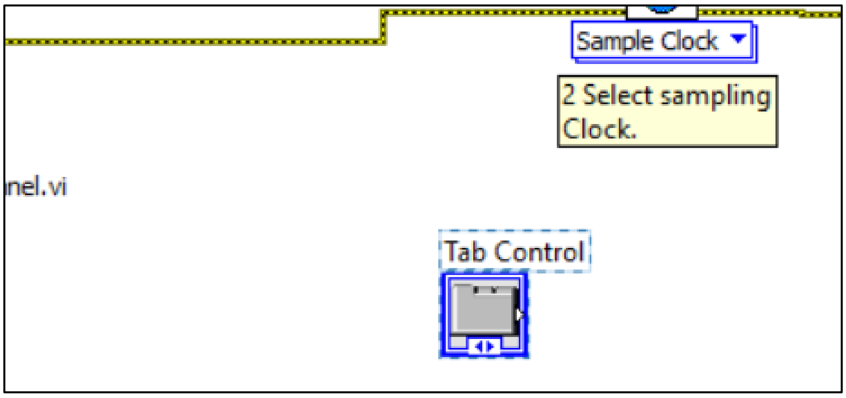


Figure 72: Tab Control function

Therefore, the development of the VI section is completed here, and as a result, the VI is ready to serve for the purpose of the observation and analysis of the real-time data of the hardware.

5.3.2 Configuration of Front Panel

Front Panel is second user interface after Blok diagram. In front panel there exist all types of displays which are used for the representation purpose. The front panel includes representation elements such as push buttons, light indicators, different types of charts and graphs, gauges, dials, indicators etc.

In the current VI Created front panel represents different dials, waveform charts, buttons to start and stop the programming as well as the initial condition windows which can be changed according to the hardware.

- **Push Button**

The representation of start stop button exist in block diagram is represented in the front panel. The purpose of the Start and Stop button provision is to control the initiation and competition of the program.

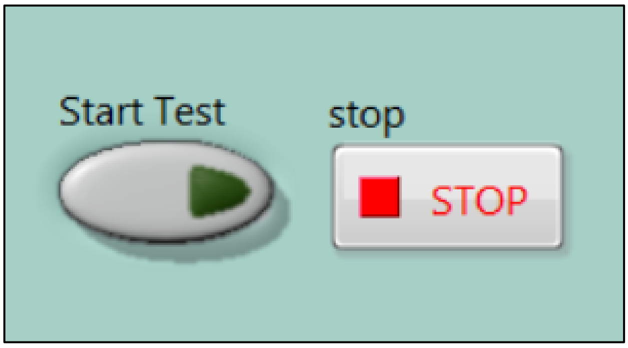


Figure 73: Start/Stop Push Button

- **Physical Channels**

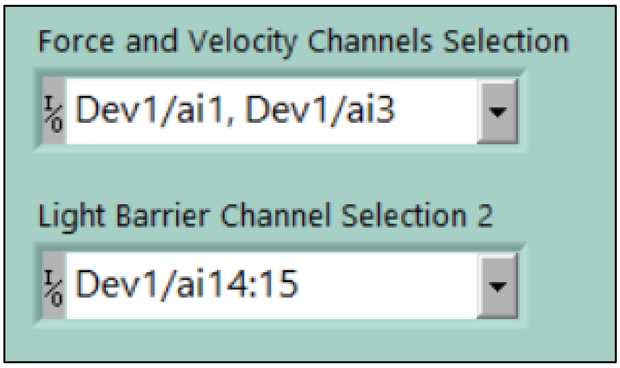


Figure 74: Physical Channel representation

The physical channels which will be used for the data acquisition are represented here in the channel selection pane. The channels can be changed according to its connection with the NI Data acquisition card. Two-two channels are separated because of their initial conditions. One icon is representing Force and velocity channel and another one represents light barriers.

➢ Coefficient Indicator

Indicators for coefficient value adjustments are shown in the screenshot. First one is milliseconds to wait control where the speed for next iteration of the graph has been decided. And it can be seen that it has been set to 10ms. The second control is a coefficient value for the calculation of the torque is shown. As mentioned in the description of the section □ it has been kept 1 after calibrating it with the hardware in the lab. The next coefficient is voltage to m/s and this value has been set to 0.421 after it has been calibrated with the current hardware setup in the lab.

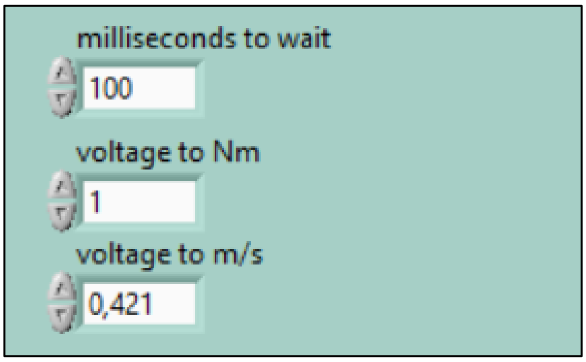


Figure 75: Indicator for coefficient

➢ Waveform chart and Dial Indicator

The waveform chart and Dial indicators are the two types of charts used in the used case. The waveform chart is used for displaying Force signal, Velocity signal, actual force, actual velocity as well as representation of the torque. For the understanding purpose only one chart is shown, and rest will be discussed in the results section. The chart maintains history of the data and hence can be exported as well to Excel. The dials provided also serves the purpose of data representation. Both the waveform chart and Dial indicator are showed in the Figure 76. As mentioned in previous section there are different forms of graphical representation options available in the front panel.

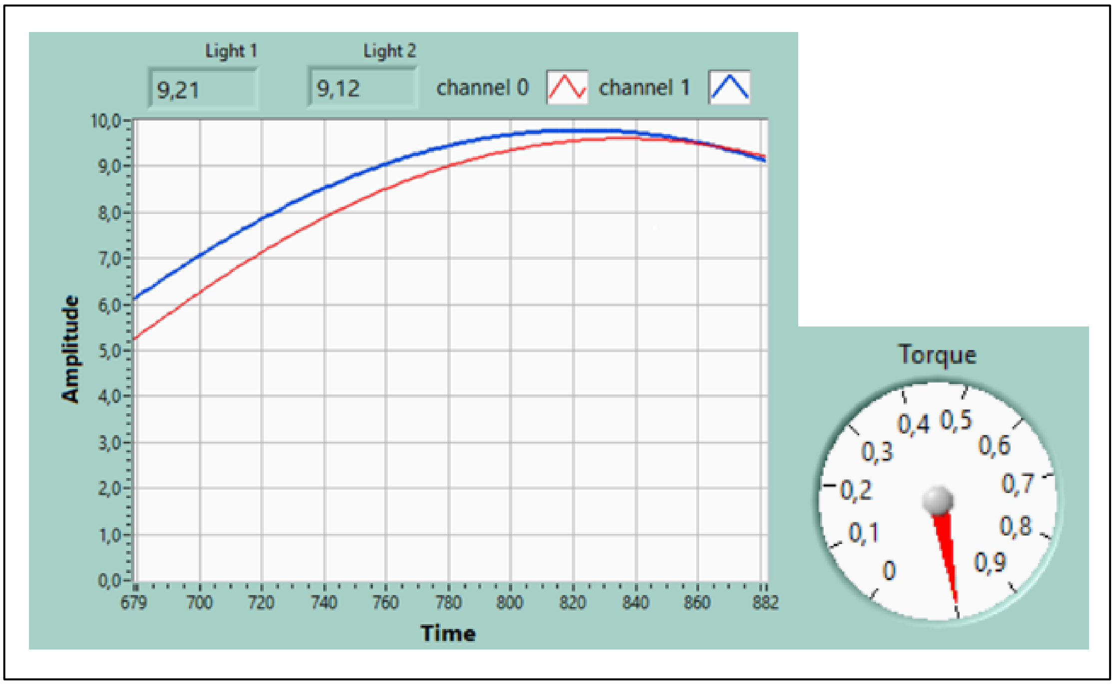


Figure 76: Indicators

The representation can also be done in form of 2D or 3D Graphs. The graphs are available under controls palette in graphs section.

Here concludes the section on setting up the block diagram and front panel, which will serve as the logic for acquiring the correct hardware signal data. In addition, this concludes the part on hardware and software configuration, and the system is now ready for data gathering application.

6 Result and Discussion

6.1 Outcome of Literature Studies

The results section gives result about two parts of the thesis. In first part literature review is carried out and is explained with one industrial example. And in second half of thesis the issue of data acquisition is addressed so to focus on points of more productivity and process optimisation.

The knowledge of literature study by means of understanding components of SCADA, understanding of SCADA is observed whether it is being followed in actual working environment. And in the detailed case description of Honeywell application, it had been observed that all the internationally designed protocols such as IEC, PLCopen are considered while designing the Experion solution. In the second section the conveyor system had been successfully implemented with the logic to calculate different parameters. Data acquisition of those parameters and monitoring of data trend was vital for carrying out system optimisation drive and to have historical data available for utilization when needed. The implementation of SCADA solution LabVIEW efficaciously generated different types of graphs which are mentioned one by one below.

The VI generated in the LabVIEW is represented in two types. First one is waveform chart and second one is in the form of Dial for continuous monitoring. The waveform chart is used to show the original acquired voltage along with the formulated output. The waveform chart is used for the acquisition Light signal 1 and 2, Velocity signal, Force signal. Then the formulae with the coefficients are applied to the received voltages to get the waveform charts of Torque and Velocity. The waveform charts can be exported to Excel for analysis and data storage, although the thesis has been restricted to running the software without glitch rather than gathering actual specimen readings. The torque is also represented using the dial indicator. The dial can be just used for the observation purpose of the signals and to note the sudden change in torque signal. The generated graphs are explained one by one in this section.

6.2 Force Signal Measurement (LabVIEW)

The first graph generated is force signal which is acquired from the signal of force transducer sensor shown in Figure 77. Two graphs are combined using Bundle VI in the block diagram to

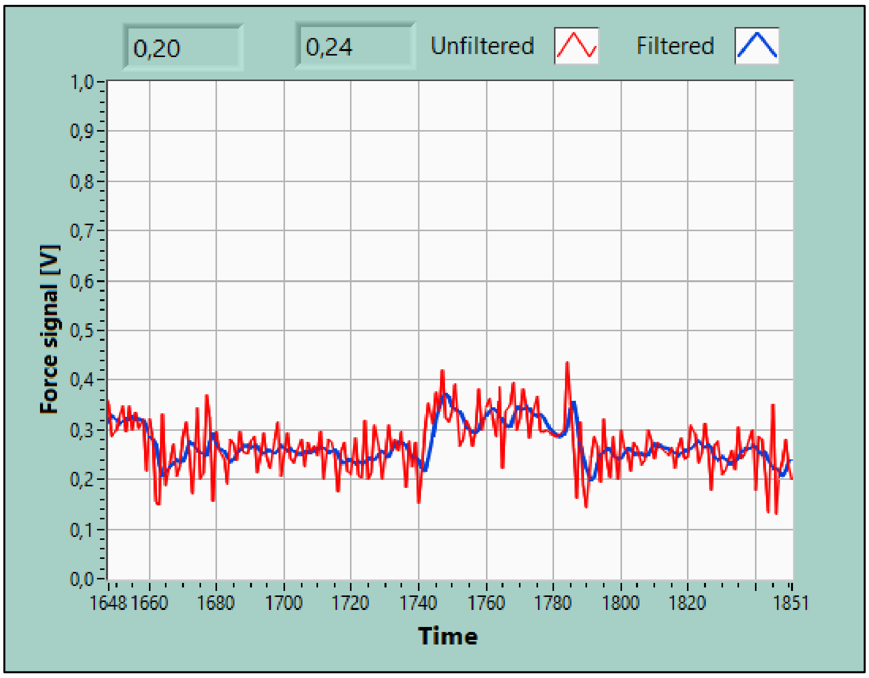


Figure 77: Force Signal

show the comparison of the filtered and unfiltered force signals. The X axis represents time in ms and amplitude of voltage is represented in Y axis. The signal depicted in red colour is unfiltered signal as can be seen more disturbance in the signal as there is noise in the signal. The noise reduction from the signal is carried using second order Butterworth filter. The filtered signal is represented in blue colour and the signal looks more stable as it contains less spike in the signal. It could be possible that the spike in the results is causing by the little collision of the container at the curves present in the conveyor.

6.3 Torque Signal Measurement (LabVIEW)

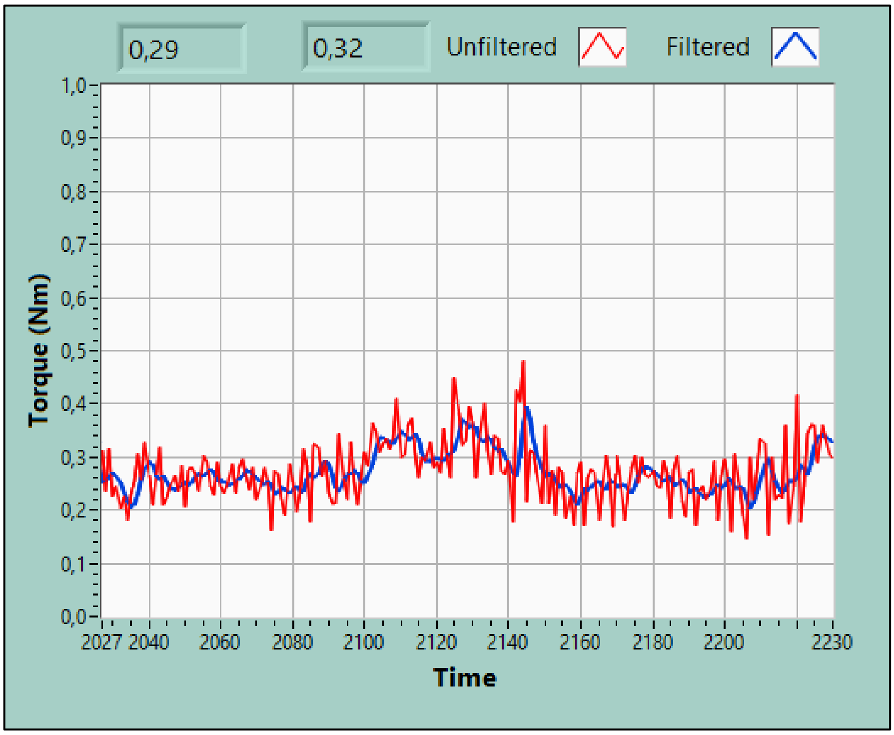


Figure 78: Torque

The torque of the motor is calculated using the same force signal and then multiplied with the coefficient value set after the calibration with the hardware. As can be seen at the X axis of the waveform chart, it exists not only time in ms but also the Y axis represents Torque in Nm. Like force signal the unfiltered signal and filtered signals are bundled for representation purpose. The unfiltered and filtered signals are represented in red and blue colours respectively. Values of the chart can then be exported to excel for data acquisition. It could here also be possible that the rise at some points in the signals is also because of the corners of containers being struck to the conveyor.

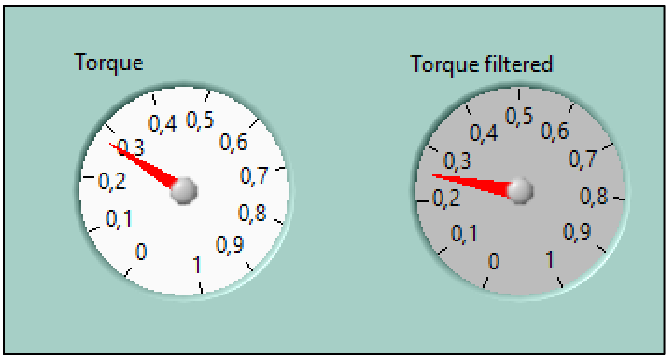


Figure 79: Dials representing torque

The data of torque motoring filtered and unfiltered can also be done using dials. Provision of dials is carried out just to observe range within which the torque is operating in real time. Here two dials are present out of one is for filtered torque measurement and another one is for unfiltered torque measurement. At the same time, it can be seen that the torque observed is close to 0.25Nm if signal is filtered and it is almost 0.29Nm when the signal is not filtered. Here it can be noticed that unfiltered signals can give more inaccurate readings than the one in filtered signals. As can be seen in the unfiltered signal the readings are slightly higher than the filtered signal as it is adding unnecessary high frequency noise in the signal.

6.4 Velocity Signal Measurement (LabVIEW)

The next observation is performed in order to acquire a waveform chart for the Velocity signal. The velocity signals are generated by Tachogenerator. This signal is used to calculate velocity with which conveyor belt revolves. These signals are then depicted in the waveform chart in Figure 80. Both the filtered and unfiltered signals are shown in the figure. The signal in Volt is calculated against the time. The filter used matches the previously used filter which is second order low pass Butterworth filter as the generated signal are maximum times have flat frequency response.

The next waveform chart is calculation of actual velocity using velocity signal acquired by the sensor. The observation window is shown in Figure 81. This chart is acquired with the use of coefficient value. The coefficient used for the calculation of velocity is 0.421. The velocity voltage is multiplied with the coefficient which has been chosen with the accurate calibration with the present hardware. In the chart in Figure 81 it can be seen that the signal generated is more or less present with minimum fluctuation. It is possible only because there is only one container with fixed amount of load is passed on the conveyor belt. If sudden load change observed, then it can hamper the output of the velocity. The velocity in m/s on Y axis against time in ms on X axis is mentioned. The trough observed in the chart below is only because at that point the setup had turned ON and justification for next trough is, at that point of time the loaded container was kept on the conveyor.

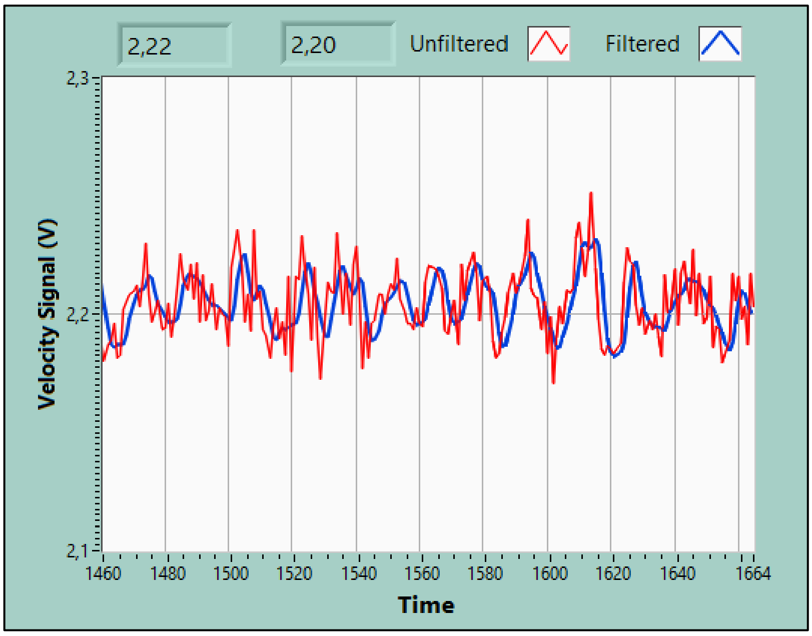


Figure 80: Velocity Signal

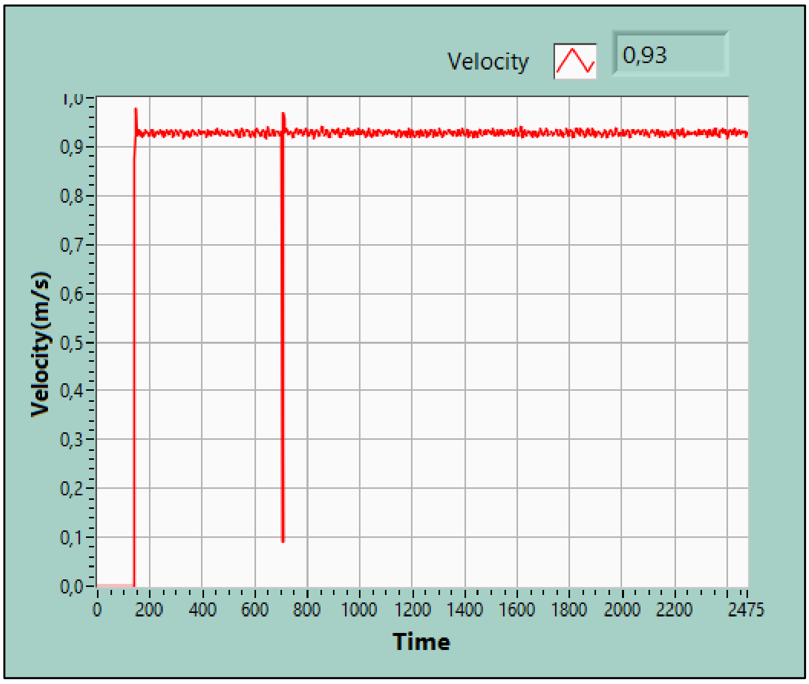


Figure 81: Velocity

6.5 Light Signal Identification (LabVIEW)

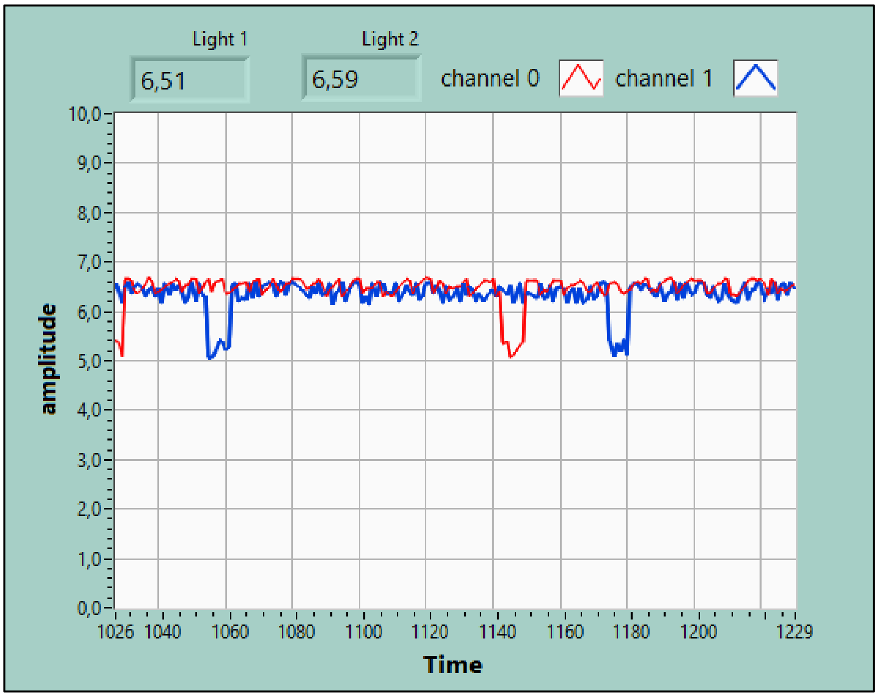


Figure 82: Light Signal

The light signal is generated using the light barrier present on the conveyor on the two ends. The light barriers are present for the detection of the container on the conveyor. Channel 0 and Channel 1 are two light barriers shown in Figure 82. The trough in the chart is the point where the container passes the sensor. Two light barrier signals are as well bundled for better monitoring purpose.

The emphasis in the creation of VI was to acquire a real-time data with the use of sensors and to create a graphical representation for the easier management of historical data for further analysis and improvement of the system purpose.

7 Conclusion and Future Work

7.1 Conclusion

The part of research conducted in the thesis on the SCADA system provides detailed information on the SCADA system components. The specifications of a SCADA system are presented using the SIMATIC SCADA system as an example. Along with HMI protocols SCADA protocols developed by IEC in industry are discussed. Current SCADA protocols are developed with statements for master station initiation and response as well as statements for RTU initiation and response keeping current SCADA protocols in mind. IEC protocols are based on enhanced performance architecture. In IEC there exist seven layers and each layer addresses specific fields such as controlling existing telecontrol systems, etc. Then in next chapter one Honeywell eco-system of component Experion is discussed the solution of has versatile working capabilities with giving maximum output and fast troubleshooting of energy generation plant related events.

In next section one existing problem of data acquisition issue from ITL is addressed, which put light on the problem occurring in data acquisition of conveyor system. The problem is then solved with using NI SCADA tool LabVIEW. The tool is used in systematic manner and then was successful to perform task of data acquisition in real time. The conveyor system present in ITL with provided LabVIEW solution gave fantastic results in the form of velocity, torque and force values. It can be stated that LabVIEW programming provides considerable benefits to any automation system. Every NI function used in creation of LabVIEW VI is explained one to one for throughout understanding of the procedure followed.

It can be concluded that Automation solution using LabVIEW is less troublesome in comparison with traditional programming environments and is scalable. The ease with which devices can be interfaced is an appealing feature of LabVIEW, especially for the ones who lack the time or experience to consider utilizing a standard programming language.

7.2 Future Scope

There is still scope in the future for detailed study of the SCADA standards using different cases. In the next case, more complex problems can also be addressed while keeping within

SCADA protocols. A new thesis focusing only on the details of SCADA standards could be carried out. The SCADA system can be explained using a case study using traditional programming methods such as C++, Python, etc.

The NI LabVIEW provides fantastic solution and very easy to comprehend therefore it can be applied to numerous intralogistics applications. The setup on which the practical is carried out at ITL TU Graz could be implemented further with other sensors. The sensors could measure pressure and temperature. The VI used for the calculation of parameters such as force, torque, and velocity can be redesigned for the calculation of acceleration, momentum, and so on. In conclusion, it would not be wrong to say that there are vast possibilities to carry out research on the same topic.

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