WinCC, Profibus and Profinet Systems for Teaching Purposes

School of Engineering and Information Technology

Bachelor Honours Thesis Project
ENG470 Semester 2 2016

Supervisor – Associate Professor Graeme Cole

Submitted by
Luke Endall

Submitted to the Murdoch University School of Engineering and Information Technology in partial fulfilment of the requirements for the Bachelor of Engineering Honours Degree.

Declaration

I declare that this Honours project report is my original work built upon the work conducted by previous Murdoch University Engineering Students.

The report was written entirely by me and all sources of information used have been referenced and acknowledged.

Signed: Date: 5-1-2017

____

Luke Endall

Acknowledgements

I would like to thank the following Murdoch University staff for their support and guidance during the project:

Project Supervisor – Associate Professor Graeme Cole

Technical Officers: Mr. Will Stirling and Mr. Lafeta 'Jeff' Laava

I would also like to acknowledge the previous students who worked on this project and produced materials that are referred to extensively in the developed Learning Modules:

Bilal Ahmad Khan (2016)

Lewis Glenister (2016)

James Wiggins (2015)

Jagan Ramasamy (2015)

Jonty Marten (2013)

Othman Bensaoud (2013)

Hao Xu (2013)

Brenton Walker (2011)

Executive Summary

This thesis project is a continuation of multiple projects that first began in 2011. In 2011, Murdoch University procured the following new technologies to introduce into the Industrial Computer Systems Engineering (ICSE) major under their Bachelor of Engineering Honours undergraduate degree:

- two industrial networking standards (Profibus and Profinet),
- remote network monitoring or supervisory control and data acquisition (SCADA) control software (SIMATIC WinCC) and,
- variable speed drives

Before these technologies could be taught, they first had to be learnt and understood. To achieve this, since 2011, students have been working with these technologies and producing learning materials to assist future students.

The primary objectives of this phase were to:

i) Research, assemble, review and simplify existing project materials and,

ii) Design and create learning modules which encapsulate the existing project materials in the form of 'Lab guides' to be used in the ICSE Laboratory Room. These materials will be used in the ENG448 SCADA and Systems Architecture Unit commencing in Semester One of 2017.

These primary objectives were achieved, with the actual learning modules delivered to the project supervisor electronically.

This report begins by introducing readers to the background of the project, its motivation and objectives for this phase in sections one and two.

Readers are then informed about the various new technologies that will be taught in the learning modules in section three and then outlined as to the approach/methodology used in achieving the project objectives in section four.

The learning modules are then discussed with specific hardware/software being introduced during each relevant learning module in section five.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

This thesis project is a continuation of multiple previous projects which date back to 2011. In 2011, Murdoch University procured multiple new technologies with subsequent hardware/software with the aim to eventually incorporate these into the Industrial Computer Systems Engineering (ICSE) major under their Bachelor of Engineering Honours undergraduate degree. These technologies consisted of:

- two leading industrial networking standards: Profibus and Profinet
- remote network monitoring or supervisory control and data acquisition (SCADA) control system architecture – SIMATIC WinCC
- variable speed drives (VSD's)

Before these technologies could be taught to students, they first needed to be learnt and understood. Over the past five years, this job has been assigned to ICSE engineering students, primarily thesis students but also third and fourth year students. These students learned about these technologies and how to use them primarily through user manuals, manufacturer support and existing public material.

It was found that these methods of learning were difficult and time-consuming, with materials often being very large (hundreds or even thousands of pages long) and not ideal for teaching students with limited to no experience using the specific technologies.

To address this, these students have been producing learning materials in the style of 'how-to' manuals for different aspects of each of these technologies. Whether it is setting up a certain piece of hardware, or writing code to program it, students have tried to develop materials that make achieving these things easier and faster than would otherwise be possible.

While many of these materials had been produced very well and were useful for their intended purpose, most had not been structured in a useable manner and with the sheer quantity of materials produced, it proved difficult for prospective students/users to find a place to start and then progress their learning in a logical/sequential manner.

To solve this problem, this phase of the project is concerned with bringing all these student-developed materials together and putting them into a format that is ready to be delivered and utilised in a teaching setting.

The motivation for this project is a new unit being introduced to the ICSE degree titled ENG448 SCADA and Systems Architecture (ENG448). This unit is due to commence in semester one of 2017. The materials compiled/developed during this phase of the project will be used as teaching materials for this unit.

The new or novel aspect of this project is the design of learning modules utilising the existing student-developed engineering learning materials. Whilst this may sound like more of an administrative job than engineering, this is not true. The existing learning materials had been developed for third and fourth year engineering students and would be extremely difficult for readers to understand let alone structure and expand upon in a deliverable teaching package without an engineering background.

The concept of this phase of the project may be viewed as being slightly different to a typical engineering thesis project since teaching materials are to be produced rather than a physical device. Although this may be true, a thorough technical understanding of numerous previously untaught technologies (from a Murdoch University perspective) will need to be achieved to allow for a carefully planned design of learning materials which both improve and expand on existing materials.

This phase of the project is extremely important – without it, five years worth of existing learning materials will not be utilised in a meaningful way. The author recognises that an enormous amount of both students' and staffs' time has thus far been invested into this project and is therefore driven to ensure that this investment is not wasted and the best return is achieved.

An important question of any thesis is its relevance - this project is extremely relevant because the time/work invested into it will result in the production of materials being used by the next cohort of Murdoch University Engineering students and potentially many more following. This project importance and accountability is not taken lightly by the author – It is recognised and embraced in an attempt to produce the best materials possible that can be readily utilised by students and academic staff alike in both the short and long term at Murdoch University.

1.1 Objectives

The primary objectives for this project are:

1. Research, assemble, review and simplify existing project materials.
2. Design and create learning modules which encapsulate the existing project materials.
    a. These learning modules are to be 'Lab Guide' styled documents that students use to guide them through practical lab exercises.

The secondary objectives, which are to be achieved if time permits are:

1. Commission, configure and test the new hardware for the ENG448 unit and subsequent learning modules.

2.0 Background

2.1 ENG448 SCADA and Systems Architecture Unit Summary

Students studying ICSE learn how to use computing technologies, both hardware and software, in operating modern industrial plants, manufacturing processes and material processing industries. ENG448 is a new fourth year unit that will build upon the concepts established in the following third year units:

- ENG311 PLC Systems (Previously ENG305)
  - Using programmable logic controllers (PLCs) in an industrial process setting.
- ENG319 Real Time and Embedded Systems (Previously ENG306)
  - Using embedded and computer-based systems for measurement and control applications.
- ENG321 Instrumentation and Communication Systems (Previously ENG345)
  - Develop knowledge and experience in using industrial instrumentation networks.

Throughout the ICSE major, students spend the majority of their contact hours in the ICSE Laboratory (Lab) which is located in room PS2.027 in the Physical Sciences building at the South Street campus, shown in Figure 1 and Figure 2. In the ICSE Lab are eight 'panels' with various hardware devices attached which students learn how to use during their studies.

ENG448 will continue the ICSE trend of being a 'practical' orientated unit utilising the ICSE Lab. Students will develop their own Profibus and Profinet networks on the ICSE Lab's panels with devices they have used in previous ICSE units. They will learn how to effectively monitor and control their developed networks using the SIMATIC WinCC SCADA control system architecture [1]. Additionally, VSDs will be introduced to students for the first time which they will also be able to connect to their industrial networks.

Figure 1 External view of ICSE Laboratory

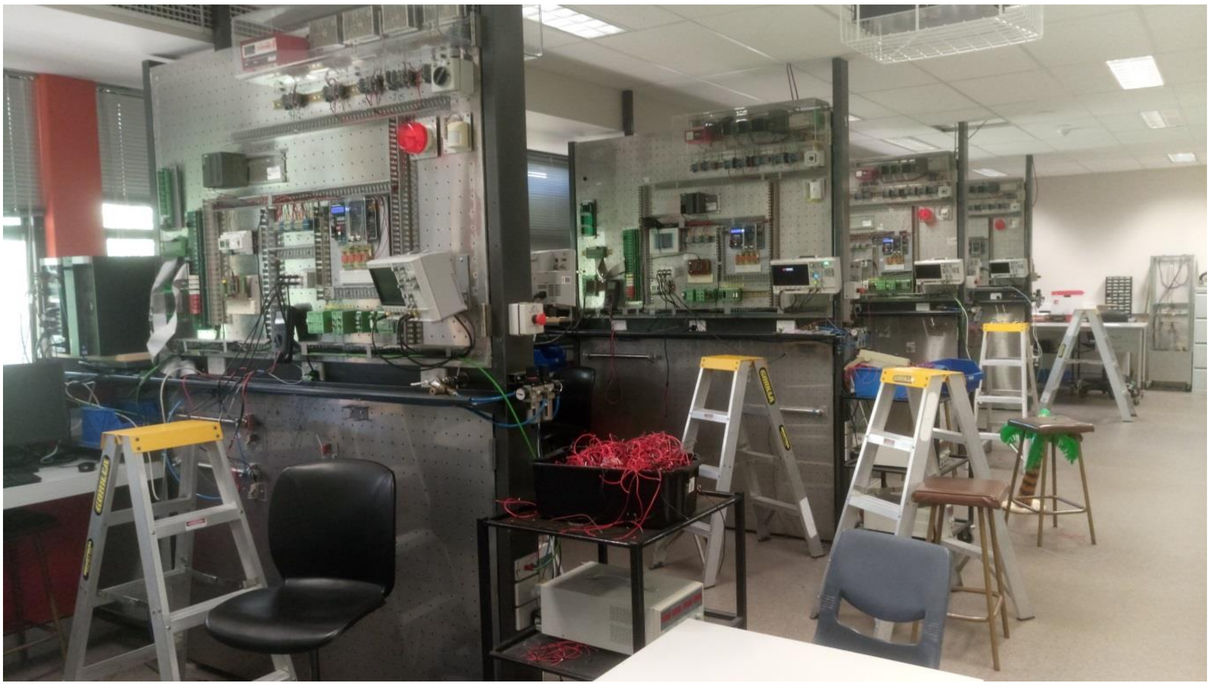


Figure 2 Internal view of ICSE Laboratory

3.0 Technologies Used

Chapter three introduces readers to the main technologies introduced in ENG448: Profibus, Profinet and SCADA. Specific hardware/software will be discussed in the Learning Modules section 5.0.

3.1 Profibus Introduction

Profibus, which is short for 'process fieldbus' is a group of industrial network protocols for fieldbus communication and automation technology [2].

3.1.1 Fieldbus

A fieldbus is a bi-directional, multi-drop real time digital communications system which allows transfer of data between devices for control and measurement [3]. For industrial settings, fieldbus is primarily used to communicate between industrial controllers and field devices like sensors and actuators. Applicable industries include the power generation, petrochemical and food industries. Before fieldbus, all elements along a production line would need to be hardwired back to a single central controller or programmable logic controller (PLC) as shown below in Figure 3.

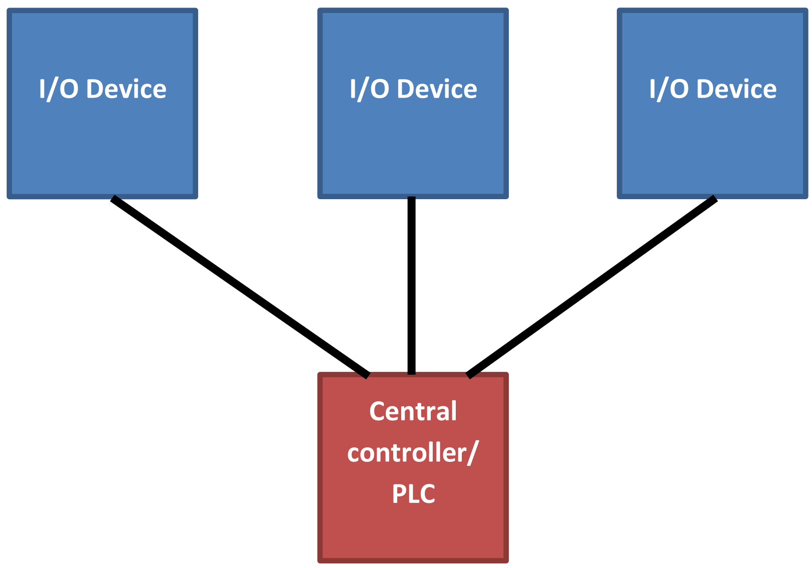


Figure 3 Illustration of an automation setup before Fieldbus, based on [4]

This approach resulted in many long runs of wire which were both costly and difficult to manage. Fieldbus addresses this by locating connection points close to input and output devices to form nodes, allowing for the easy addition of input and output devices which would otherwise need to be fed back to the central PLC. Instead of having many wires connected to the controller, a single cable, or 'bus', which all the network nodes attach to is used [4] as shown below in Figure 4.

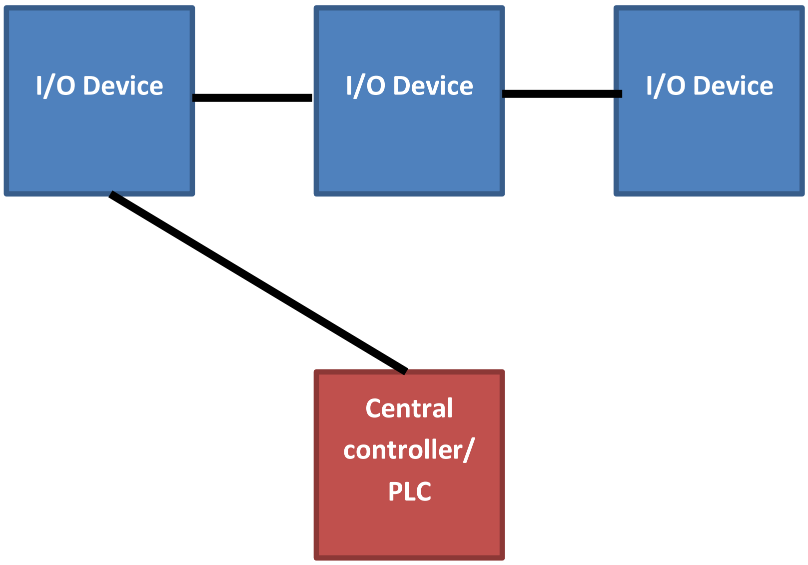


Figure 4 Illustration of an automation setup using Fieldbus, based on [4]

3.1.2 Types of Profibus

Profibus was first introduced in 1989 by the German Department of Education with Siemens being the first company to conduct research into it [5]. As different applications require different network characteristic, there are multiple Profibus network protocols.

There are currently two types of Profibus: Profibus DP (decentralised peripherals) and Profibus PA (process automation) [5]. In this project, Profibus DP is used however Profibus PA as well as the first type of Profibus – Profibus FSM will briefly be discussed in the following sections to provide context. Profibus DP will then be discussed in more detail. Because of the available hardware and PA's limited applications (only used for process applications) with DP being much more common in industry [6] Profibus DP was chosen to be used for this project in 2011 when the project first began [7].

3.1.2.1 Profibus FMS

Profibus FMS was the first form of Profibus introduced in 1987 [5]. It was created jointly between 21 German companies and institutions (who became known as the Central Association for the Electrical Industry, ZVEI) [5], in an aim to create a bit-serial Fieldbus system that could replace traditional 4-20mA current loop systems [2]. Digital communication technologies, like bit-serial Fieldbus systems, were capable of transmitting more detailed information than 4-20mA systems and were therefore seen as the future. The goal of FMS was to have the ability to include more hierarchical systems by transferring advanced data from PC to Master devices in a peer-peer fashion (also between masters). FMS is rarely used today as it is not very flexible and is not suited for less complex messages as well as communication for larger networks. Simpler protocols have hence been produced and FMS's primary function of facilitating peer-to-peer communication has largely been replaced by Ethernet-based protocols [6].

3.1.2.2 Profibus DP

Later in 1993, ZVEI introduced Profibus DP (Decentralised Peripherals) [5] which allowed for easier configuration and faster messaging. Since this is the form Profibus used in this project, it will be discussed in detail in section 3.2.

3.1.2.3 Profibus PA

Profibus PA was designed for use in the Process Automation industry. This protocol is actually an application profile of Profibus DP so it shares some similarities. The primary differentiating factor of Profibus PA is that it was designed to be used in hazardous environments [5].

RS-485, like Profibus DP, is used as the physical medium for data transfer in the majority of environments however in explosive environments RS-485 is replaced with Manchester Bus Powered technology (MBP). This is used because Profibus PA supports power-over-bus which can potentially create sparks resulting in explosions in such explosive environments. MBP addresses this by stepping down the power to smaller levels to virtually eliminate the possibility of an explosion [2].

3.2 Profibus DP

Since Profibus DP was chosen for this project, this section will discuss the technology in more detail. From here on in the report, Profibus DP will simply be referred to as Profibus.

3.2.1 Open Systems Interconnection (OSI) Model

Profibus is an open standard which is vender-independent to facilitate compatibility of any connected device. It also adheres to the Open Systems Interconnection (OSI) Model [5] to ensure multi-vendor device operability. The OSI model describes the communication functions of specific communications and computing systems with an aim for interoperability between different standard protocols. A protocol is simply a type of 'language' that computers communicate with each other with [5] – just as there are many languages spoken by humans the same applies for computers and digital equipment.

Referring to Table 1 below, the OSI model has seven layers, which each describe a different aspect of data communication. Layers one to four can be described as network-oriented layers whereas the top layers five to seven are 'user-oriented' layers.

Table 1 Profibus OSI Layers, based on [5]

	User Program		Application Profiles
7	Application Layer		Profibus DP Protocol (DP-V0, DP-V1, DP-V2)
6	Presentation Layer		Not utilised
5	Session Layer		
4	Transport Layer		
3	Network Layer		
2	Data Link Layer		Fieldbus Data Link (FDL), either: i) Master Slave ii) Token passing
1	Physical Layer		RS-485, fibre optic or MBP
OSI Layer Model			OSI implementation of Profibus

Profibus utilises three of these layers, namely:

- Layer One – Physical Layer
- Layer Two – Data Link Layer
- Layer Seven – Application Layer

Each of these layers and how they apply to Profibus will be discussed in the following sections.

3.2.1.1 Layer One – Physical Layer

The physical layer refers to the electrical and physical specifications of devices including: cable, connectors, repeaters and hubs.

Bus Cable

The physical layers of Profibus can be utilised by one of three network methods: electrical (copper wire or MBP), optical or wireless.

For this project a standard copper wire electrical network was used as this was the cheapest and most readily available transmission medium. Additionally, an electrical network already exceeded the criteria for an introductory educational setting in terms of speed and scalability.

Electrical Profibus utilises the RS-485 physical layer [5]. RS-485 is a serial communications standard, with serial meaning one data 'bit' is sent at a time [8].

It uses shielded twisted-pair cabling which is a type of wiring utilising two conductors which are twisted together. The twisting cancels out electromagnetic interference from external sources like electromagnetic radiation which can be produced by unshielded twisted pair cables and crosstalk between nearby wire pairs [9].

For most applications, Profibus 'Type A' cable is used. Referring to Figure 5, this cable consists of two copper wires housed in a cable with a violet colour.

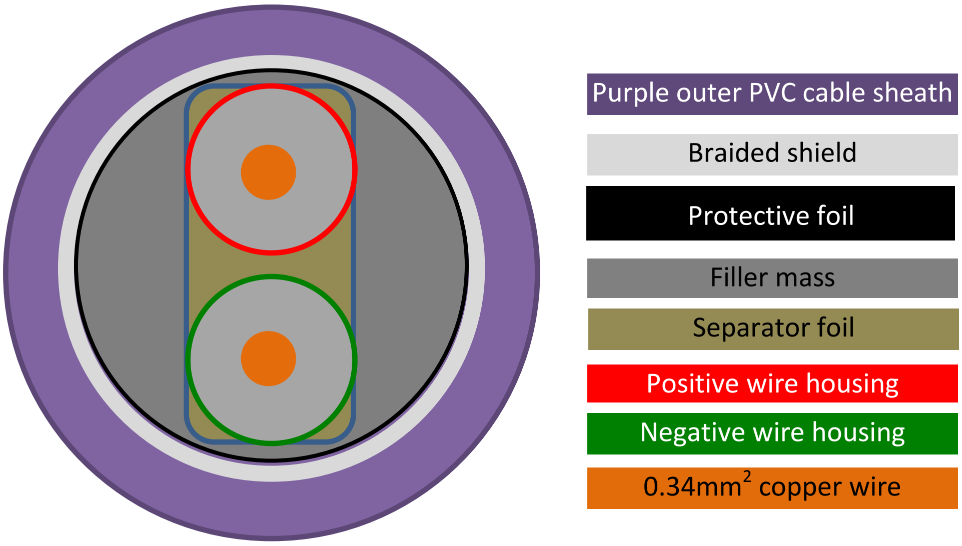


Figure 5 Profibus Type A cable structure, based on [7]

The transmission speed, or baud rate, of Profibus is dependent on the length of the cable. Referring to Table 2 below, Profibus can achieve a maximum baud rate of 12.0 Mbit/s, however this limits the bus cable to a maximum of 100m. If slower baud rates are used, Profibus cable can extend up to 1200 m in length.

Table 2 Profibus baud rate Vs maximum segment length, based on [10]

Baud Rate	Maximum Segment Length (m)	
9.6 kbit/s	1200	Slow Speeds
19.2 kbit/s	1200	
45.45 kbit/s	1200	
93.75 kbit/s	1200	
187.5 kbit/s	1000	
500.0 kbit/s	400	
1.5 Mbit/s	200	
3.0 Mbit/s	100	High Speeds
6.0 Mbit/s	100	
12.0 Mbit/s	100	

When data is transmitted over Profibus cable, reflections need to be minimised. Reflections are when the data transmitted 'bounce' once it reaches the end of the cable due to a 'discontinuity'. A discontinuity is simply a change in resistance, capacitance or inductance [7]. Termination resistors are used to achieve this which in most cases are integrated into the D-type cable connector as shown below in Figure 6.

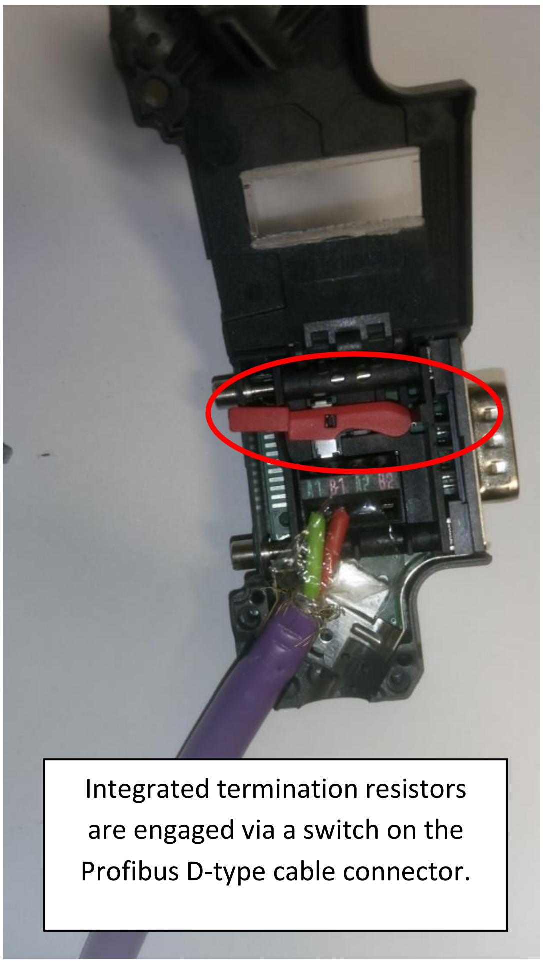


Figure 6 Profibus RS-485 D-type connector

3.2.1.2 Layer Two – Data Link Layer

The datalink layer uses a master-slave media access control (MAC) for a single master system while 'token passing' is used for multi-master systems. Since only single master systems are used in this project this will be the only MAC discussed in this section.

Master-slave involves having a single master device control all communication between connected slave devices [11]. The master communicates to each slave device, one at a time and asks for a response from each master device before progressing to the next. This process is illustrated below in Figure 7.

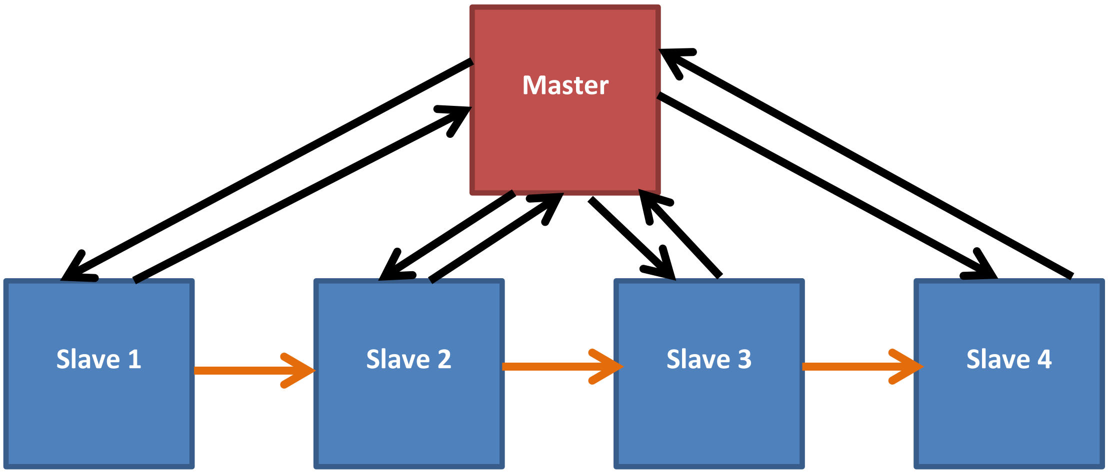


Figure 7 Master-slave communication illustration, based on [11]

3.3 Profinet

Profinet is an industrial automation networking standard which is based on Ethernet. It is used in applications such as motion control and process automation [12].

While Profibus only uses three (two from layers one to seven plus a 'user' layer) OSI layers, Profinet utilise layers one to four and seven, as shown below in Table 3, making it a more complex form of protocol.

Table 3 Profinet OSI layers, based on [13]

OSI Layer	Non time-critical communication	Real-time communication
7 - Application	Profinet Application Layer	
6 – Presentation Layer		
5 – Session Layer		
4 – Transport Layer	TCP/UDP	Profinet Real-time channel
3 – Network Layer	IP	
2 – Data Link Layer	Standard Fast Ethernet IEEE802.3	
1 – Physical Layer		

The physical and data link layers utilise Ethernet technology that adheres to Electronics Engineers (IEEE) 802.3 standard. Although you can use standard Ethernet, this does not support realtime data transfer which Fast Industrial Ethernet [12] is required for, allowing for operating speeds of 100Mbit/s which is much faster than Profibus [12].

Profibus is half duplex (communication can occur in two directions but only one way at a time) while Profinet operates at full duplex [14], meaning data can be sent in two directions simultaneously [15].

The physical cabling is either twisted copper pair or fibre optic cables. For copper cables, RJ-45 connectors are used, as shown below in Figure 8.

Figure 8 Profinet cable with RJ45 connectors

For non real-time communications, Profinet utilises the TCP/IP layer as well as other standard IT protocols. Non real-time is considered to have cycle times of greater than 100ms. An example of non real-time monitoring is that of temperature [16] [17].

For realtime data, which can be defined as having cycle times of less than 10ms, a dedicated high-speed path is provided which bypasses the TCP/IP layers in the form of a ‘real-time channel’ [17].

For applications that require extremely high transfer speeds like motion control, Isochronous Real Time (IRT) data transfer is used. Isochronous means each cycle begins with the same interval, achieving cycle times of down to a minimum of 31.25 microseconds [17].

Unlike Profibus which uses a ‘bus’ network, Profinet uses switched networks where devices are connected via switches [17] which facilitate point-to-point communication. A switch is comprised of a number of ports which individual devices connect to. Standard network switches can be used or more advanced managed switches which provide advanced diagnostics. Switches occur at the Data Link layer two of the OSI model which is a form of MAC addressing.

3.4 SCADA

ENG448 will introduce students to a piece of software called SIMATIC WinCC Runtime Professional (WinCC) developed by Siemens. It is a form of Supervisory Control and Data Acquisition (SCADA) system. Before WinCC is discussed, SCADA will first be introduced in the next section. WinCC is discussed in the WinCC Learning Module section 5.2.

3.4.1 Introduction

Supervisory Control and Data Acquisition (SCADA) systems are used to monitor and control plants in energy, water and waste, telecommunications, transportation and oil and gas refineries [18]. They operate by transferring data between a central SCADA configured host computer, remote terminal units (RTU’s) and operator terminals via a communications system [19] [20].

Conceptually, a SCADA system will gather information related to the monitored plant and send this to the central host computer. This information will then be displayed to the operator in an intuitive manner who can then use this in determining if action (control) of the plant needs to be taken.

Although historically, SCADA systems were made up of dedicated industrial networks (ENG448 uses SCADA in this context), modern SCADA systems can utilise corporate Local

Area Network (LAN) networks [20] for geographically close plant setups and Wide Area Networks (WAN) for more distributed systems as well as wireless technologies [20].

3.4.2 Parts of a SCADA System

Refering to Figure 9, typical SCADA systems can be broken up into four distinct parts [20]:

1. Field Data Interface Devices

   These are devices that connect to the actual sensors/actuators of the plant. They are usually in the form of remote terminal units (RTUs) or PLCs. RTUs are electronic devices consisting of microprocessors that transmit data between their connected devices and a connected host computer which monitors and controls the devices remotely. Although RTUs and PLCs are technically different devices, they often serve the same purpose. PLCs are discussed in the '5.1.2 S7-300 PLC' section.

   Field data interface devices convert the electrical/electronic signals from field devices to the communication protocol of the network. In ENG448 it is intended that PLCs will be primarily used for this purpose however a specific RTU is also introduced.

2. Communications System

   Used to facilitate the transfer of data between the field data interface devices and central host computer. These can be in the form of cable, telephone, radio and satellite systems [20].

   The communication systems used in ENG448 are Profibus and Profinet networks or a combination of both.

3. Central Host Computer

   The central host computer, often referred to as a master station, can be a single computer or a network of computer servers. It processes the information sent to and received from the field data interface devices and presents this information in a form that is useable by human plant operators. This information is also stored in a database for presentation of historical values / trends.

4. Operator Workstations / Software Components

Operator workstations are computer terminals connected to the central host computer. The central host computer is the SCADA application server which the client operator terminals can request/send information to, controlled by the operators.

Software components allow computers to be configured as SCADA servers/HMIs. Process visualisation (via tables/graphs), trending (via historic values) and alarms (when process limits are reached) can also be implemented in these. Often the SCADA system is designed and configured using such software.

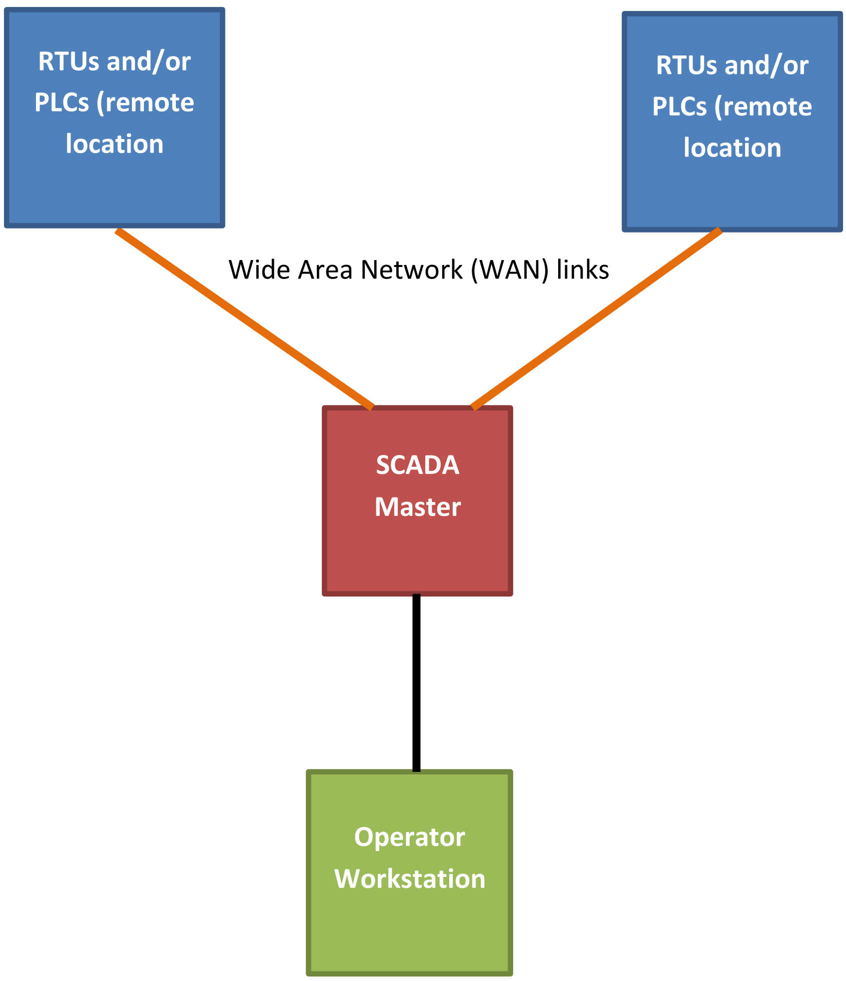


Figure 9 Example SCADA layout, diagram based on [20]

3.4.3 Security

The main problem with SCADA systems is security. Since SCADA has been developed to be an open-platform facilitating interoperability between any device, this development approach results in an insecure system [20]. This is of particular concern if the SCADA network is integrated into existing office networks where unpermitted staff could gain access or even members of the public if this network is connected to the internet. There have been cases where SCADA systems have been attacked [18] [20] by external sources which have resulted in the development of more secure networks [18] [20]. Unfortunately progress in this area has so far been limited.

4.0 Description of Technical Aspects

This section describes how the project was conducted during this phase to achieve the objectives listed in section 1.1.

4.1 Approach

The approach taken to achieve the objectives of this project consisted of three key elements:

1. Utilise as much developed materials as possible
2. Present the learning modules in a manner that is easily understood by students
3. Strike a balance between guided examples and application-style questions

Each of these elements will be elaborated upon in the following sections and also described as to how they were achieved using examples from sections of the actual developed learning modules.

4.1.1 Utilise as much developed materials as possible

At the commencement of this phase of the project it became clear that are very large quantity of learning materials had been produced by previous students for this project. Although it proved difficult to navigate through these various materials, it was desired to utilise as much of it has possible. This material had been developed by students for students and was much easier to follow than the user manuals for the specific technologies/devices and would work very well in an educational setting. It would be such a waste to not use as much of this as possible.

To utilise as much developed material as possible despite the difficulty of the sheer quantity of materials, it was decided to use different types of student-developed materials for different purposes/applications. It was intended that this would structure the materials into different sections to prevent students being overwhelmed with large quantities of seemingly unstructured materials and not knowing where to start and subsequently progress to.

4.1.2 Thesis Reports

Since the majority of work for this project had been conducted by previous thesis students, there were multiple thesis reports subsequently produced. In these reports, students were required to introduce readers to the technologies they used and to explain them in detail.

This particular content within the multiple thesis reports was therefore integrated into the learning modules as introductions to the particular technologies used in each individual module. This manifested in the form of a 'Preliminary Reading' section at the beginning of every learning module where students are referred to sections of multiple thesis reports to read before they physically use the technologies in the ICSE Laboratory sessions.

This was considered a very important part of the learning modules because a theoretical understanding of the particular technology/device being introduced in each learning module is essential for efficient progress through the practical exercises in each lab session as well as understanding what is actually happening in these.

Since the thesis reports presented the technologies from a student perspective, drawing from many different references, they served as easy to follow readings that would save students many hours researching the technologies themselves.

See Figure 10 and Figure 11 below which use an example from the 'Siemens HMI Touch Panel' learning module illustrating how the Preliminary Reading section refers students to sections of various thesis reports. The actual sections of reports are not included in the specific learning module's Word document (to save space and retain document simplicity) but are hyperlinked at the start of the learning module document with the actual documents being stored in a 'Thesis Reports' folder.

Siemens HMI Touch Panel

1.0 Preliminary Reading

James Wiggin's Thesis:

[1] J. Wiggins, "Development of a WinCC and Profibus System for Teaching Purposes," Honours Dissertation, Murdoch Univ., Murdoch, WA, Australia, 2015. **Section 3.1.3 page 19 and Chapter 7 pages 49 - 54.**

Bilal Ahmed Khan's Thesis:

[2] B. A. Khan, "WinCC SCADA and Profibus Network for Murdoch University Engineering Laboratory," Masters dissertation, Murdoch Univ., Murdoch, WA, Australia, 2016. **Section 3.6 Pages 57 – 58.**

Hao Xu's Thesis:

[3] H. Xu, "WINCC SCADA SYSTEM VIA PROFIBUS & OPC," Honours Dissertation, Murdoc Univ., Murdoch, WA, Australia, 2012. **Page 46.**

Figure 10 Preliminary Reading section taken from the 'Siemens HMI Touch Panel' learning module.

Chapter 7 Siemens HMI Touch Panel

This chapter aims to provide information about the Siemens TP 177B 6" PN/DP HMI touch panel [30] that was configured to the Profibus-DP network as shown in Figure 7.1. The touch panel was configured as a HMI for the network by reading and writing data to and from the master PLC with the use of graphics. To integrate the HMI touch panel into the Profibus-DP network, both hardware and software configurations had to be developed. The following sections in this chapter aim to describe the purpose of each configuration step. For the complete list of steps taken to configure the Siemens TP 177B 6" PN/DP HMI touch panel, please refer to Appendix D: Siemens HMI Touch Panel Profibus Configuration Guide.

Figure 11 The beginning of the actual thesis report [29] referenced in Figure 10.

4.1.3 Configuration Manuals

For several of the thesis projects a deliverable was a set of 'configuration manuals' which were included in the appendices of their reports. These configuration manuals are documents that describe how to achieve a certain goal using the new technologies. These include:

- the initial setup/configuration of devices/hardware
- connecting these devices to networks and,
- communicating between devices.

It was decided that these documents would be used as guides for the actual lab exercises students would complete during the learning modules. This was because they demonstrate how to achieve individual aspects/applications related to the technologies in each specific learning module.

Figure 12, below, shows an example taken from the same 'Siemens HMI Touch Panel' learning module discussed in the previous section. It shows how many of the individual lab exercises make reference to the student-produced configuration manuals to guide them through completing the exercise. Again, the instructions detailed in the configuration manuals were not included in the actual learning module Word documents as this would make the documents very large and difficult to follow (some configuration manuals are over 30 pages long). Instead, simply the goal is stated for each exercise and then any section/s of the relevant configuration manual/s is referenced using a hyperlink, like the one shown in Figure 13.

3.0 Laboratory Exercises

1. Follow the steps on Pages 1 – 3 of the 'Siemens HMI Touch Panel Profibus Configuration Guide' document to install the HMI hardware.
    a. Be sure to terminate both the S7-300 and HMI connectors via their switches.
2. Follow the steps on Pages 4 – 14 of the configuration guide to configure the software of the HMI.
    a. Be sure to set the Profibus address of the HMI to 3 (it can be any address up to 32 or even 127 if repeaters are used but ensure that the address is unique for the network).
3. Follow the steps on Pages 15 – 19 of the configuration guide to program the HMI using Siemens SIMATIC TIA Portal.
4. Create a HMI screen that monitors the inputs and outputs of the connected S7-300 PLC.
    a. Test the screen using watch tables and/or switches and PLC lights
5. Expand the HMI screen to also allow for control of the S7-300's inputs and outputs.
    a. Test the screen using watch tables and/or PLC lights

Note: For troubleshooting network problems or difficulty in downloading programs to the HMI, see page 20 of the configuration guide.

Figure 12 Laboratory Exercises section taken from the 'Siemens HMI Touch Panel' learning module.

Siemens HMI Touch Panel Profibus Configuration Guide

This section documents the steps used to setup and configure the Siemens TP 177B 6" PN/DP HMI touch panel for a Profibus network as part of the thesis project. Provided in this section is the physical wiring and software configuration of the touch panel as a HMI on the network.

Configuring the Siemens HMI Touch Panel

The Siemens HMI touch panel can only be added to an already existing Profibus master-system. For details on how to create a new Profibus network with a Siemens S7-300 PLC as the master, please refer to the ***"Siemens S7-300 PLC & RS-485 Repeater Profibus Configuration Guide"*** as part of this thesis project before configuring the Siemens HMI touch panel.

HMI Touch Panel Hardware Installation

For this project, the ***Siemens TP 177B 6" PN/DP*** HMI touch panel was used. Figures 1, 2 and 3 show the appearance and components of the touch panel that was used.

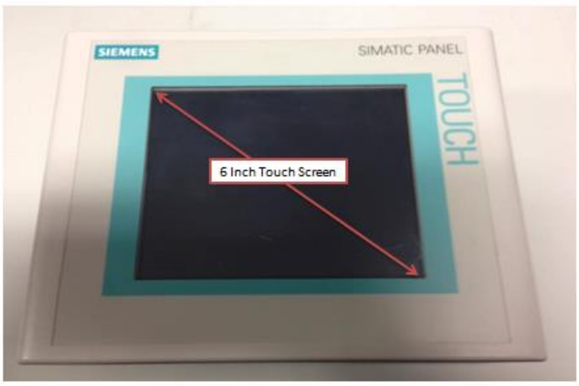


Figure 13 The beginning of the actual configuration manual [76] referenced in Figure 12.

Any referenced configuration manuals in a learning module were stored in the specific learning module's folder (see Figure 14).

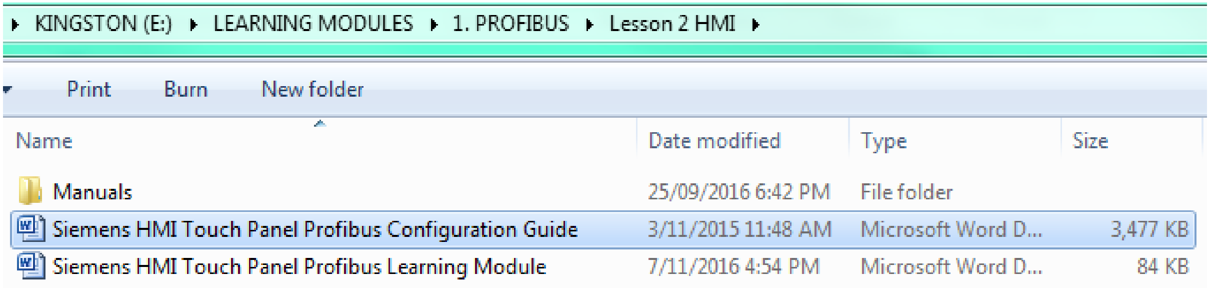


Figure 14 Configuration guides were stored in the specific learning module's folder.

4.1.4 Difficulties Experienced

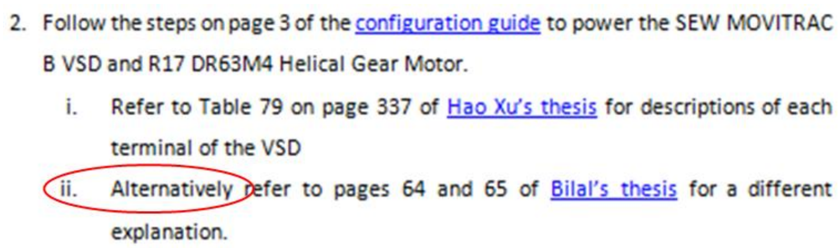
Duplicate Materials

A result of the large quantity of materials developed by previous students was that there were some duplicate materials. These materials were not simply copies of one another but were produced by different students to achieve or demonstrate the same concept. This was likely due to students not being made aware of certain materials developed by a previous student and subsequently they would produce a document that closely mirrors the older document produced by another student.

To address this, where there were multiple documents relating to the same concept, the applicable learning module would make reference to the most complete, easy to follow and most recently produced document. This was achieved by working through each of the documents (although not necessarily conducting the practical activities) and deciding which was best suited.

To achieve the element of utilising as much material as possible, the second document would also be referenced in the same learning module but rather as an 'alternative approach' to the same exercise. This would provide students with multiple ways of achieving lab exercises if they felt one instructional was not ideal. This is quite relevant for engineering problems because there is almost always more than one way of solving a problem given to an engineer. By providing students with various approaches taken by previous students, they can then decide which approach they prefer or simply expand their understanding of the topic by tackling the exercise in a different way.

A simple example of this is shown below in Figure 15 below. Both thesis reports covered a description of the SEW MOVITRAC B VSD's terminals, however Xu's [21] was more complete whereas Khan's [22] was easier to follow, showing only the relevant terminals for that specific exercise. Since both were deemed useful, they were both included in the learning module. It is hoped that this approach will provide students with additional information without overwhelming them with too much information relating to the same concept.



2. Follow the steps on page 3 of the configuration guide to power the SEW MOVITRAC B VSD and R17 DR63M4 Helical Gear Motor.
    i. Refer to Table 79 on page 337 of Hao Xu's thesis for descriptions of each terminal of the VSD
    ii. Alternatively refer to pages 64 and 65 of Bilal's thesis for a different explanation.

Figure 15 An example of multiple materials being referred to for a single learning module exercise. Taken from the 'SEW Eurodrive MOVITRAC B VSD' Learning Module.

Dated Materials

Since some of the materials for this project were produced as far back as 2011, some could not be used as their content was out-dated. This was most notable for materials that referred to and used particular pieces of software. With the nature of software constantly being updated/upgraded, some materials used software that had been upgraded by the university and were hence unusable.

An example of this was a student-produced WinCC tutorial that used a previous version of Siemen's SIMATIC software. In the years following this student's tutorial, the university upgraded to Siemen's SIMATIC TIA Step 7 Professional V13 [23] deeming their tutorial out of date. In saying this, often the later produced tutorial using the new software would actually make reference to and build upon the work done by the earlier student, so their work was still implicitly referred to.

4.1.2 Present the learning modules in a manner that is easily understood by students

This section describes how element number two of the approach to this project was achieved whilst also providing examples of this from the developed learning modules.

4.1.2.1 Background Readings

As discussed in the previous section, every learning module begins with a 'Preliminary Reading' section to introduce students to the technology/concepts that will be covered in the practical lab sessions from a theoretical point of view.

4.1.2.2 Produced Additional Materials

For topics that were not covered adequately, additional materials were produced during this phase of the project to address this. An example of this is taken from the 'SEW Eurodrive MOVITRAC B VSD' Learning Module shown below in Figure 16. An additional document was prepared to supplement the existing references chosen for the 'Preliminary Reading' section. It was felt that the concept/purpose of VSDs was not covered very well and since students have never been exposed to these devices in previous units it was considered essential that they be provided sufficient background information to introduce them to this technology.

Introduction to VSDs and Gateways

1.0 Introduction

1.1 What is a VSD?

A variable speed drive (VSD) is a piece of equipment which regulates the speed and torque (rotational force) output of an electric motor [1]. Motors without a VSD can be controlled by:

1. A valve that regulates the flow of fuel or a vane controlling airflow into the motor
2. The use of two-speed motors
3. Periodic on-off switching

However these methods are not energy efficient and with over 65% of industrial electrical energy being consumed by motors [1], VDSs are an invaluable resource.

Figure 16 The beginning of the 'Introduction to VSDs and Gateways' document produced during this phase of the project to introduce students to VSDs.

4.1.2.3 Describe what the student is doing in each lab exercise and why they are doing it

It was considered important that throughout the learning modules, students are constantly reminded of what they are trying to achieve in each lab exercise and how it fits into the larger scheme of the lab/learning module. To do this, rather than simply refer the student to a section of a configuration manual, the exercise questions are constructed in a manner that states what they are to achieve for each particular exercise and why they are trying to achieve it.

An example of this is taken from the 'SEW Eurodrive MOVITRAC B VSD' Learning Module. Referring to Figure 17 below, question six of the learning module asks the student to connect a VSD to a DFP21B Gateway. They are informed what the gateway is used for (to connect the VSD to the Profibus network) and how it achieves this (by interfacing with the VSD via an attached FSC11B Communication Module which communicates to the VSD using the manufacturer, SEW's, proprietary protocol called 'SBus' [24]).

Profibus – Module 5 – SEW VSD

6. Follow the steps on Pages 4 – 5 of the configuration guide to connect the VSD to the **DFP21B Gateway** (the gateway will be used to connect the VSD to the Profibus network). The gateway interfaces with the VSD via the **FSC11B Communication Module** using SEW's proprietary protocol '**SBus**'.
   i. For an alternative method, refer to pages 358 and 359 of Hao Xu's thesis
   ii. Remember to set the Gateway Profibus address to 5 to prevent addressing clashes.
   iii. Refer to pages 341 and 339 of Hao Xu's thesis for a terminal summary of the DFP21B Gateway and FSC11B Communication Module respectively.

Figure 17 Lab exercise six from the 'SEW Eurodrive MOVITRAC B VSD' Learning Module

This constant reminding of what the students are doing and why they are doing it was deemed extremely important because the learning modules were not intended to simply be a document that refers students to different materials. They were designed to be informative and descriptive such that they could be used as unit notes for students to look back on when studying earlier modules and refreshing themselves as to what they achieved during the labs.

4.1.2.4 Multimedia Learning Materials

In the later stages of this phase of the project, it was decided to incorporate multimedia materials to help facilitate the learning of students. Since time did not permit for the production of videos tailored to each individual learning module, existing public material on the internet was explored. As a result, numerous YouTube videos are referenced throughout the learning modules in the form of hyperlinks. Examples include:

- Videos referenced in the Preliminary Reading section of modules visually explaining how the Profibus and Profinet protocols work [25] [26] with one using vehicle traffic analogies [27] . This facilitates a better theoretical understanding of how these two network standards work.
- A video visually showing how to connect Profibus DP cable to Profibus DP connectors [28]. This video demonstrates how to actually complete a learning module lab exercise step by step where students attach a Profibus D-Type connector to Profibus cable.

So whether it was to better understand a concept or even to demonstrate how to actually achieve a specific lab exercise, these videos aimed to present the learning materials in a more engaging manner. They often presented concepts in an easier and faster way to understand than by reading a document in isolation. The videos do not replace the written materials presented/referenced in the modules but rather supplement/support them.

4.1.3 Strike a balance between guided examples and application-styled questions

With ENG448 being a fourth year engineering unit, it was deemed important that students be exposed to work/problems in a manner that is similar to what they could expect to experience once they graduate and begin working as professional engineers to better prepare them for the workplace.

While the configuration manuals served their purpose well in guiding students through individual 'baby steps' to achieve certain goals, this is not representative of the style of work professional engineers conduct in the workplace.

When a professional engineer is asked to solve a problem, they are not given an 'instruction manual' detailing each individual step to solve a problem – they are given an objective and are expected to use their engineering knowledge/skill/tool set to develop a solution that achieves the specified objective.

To get students thinking more like professional engineers, project/assignment exercises were developed which do not refer to any manuals but instead ask the students to develop solutions which meet certain criteria. The students are expected to use what they have learnt in earlier learning modules and earlier parts of the current module to develop a solution to the given problem (exercise), just like they would in the workplace. These open-ended engineering style questions (usually referred to as design studio style questions) were often constructed using previous thesis students' reports as templates for the lab exercises. This is because these reports would often describe what the author managed to achieve during their phase but would not walk the reader through every individual step taken to reach the achievement. These 'achievements' were used as application exercises in the learning modules.

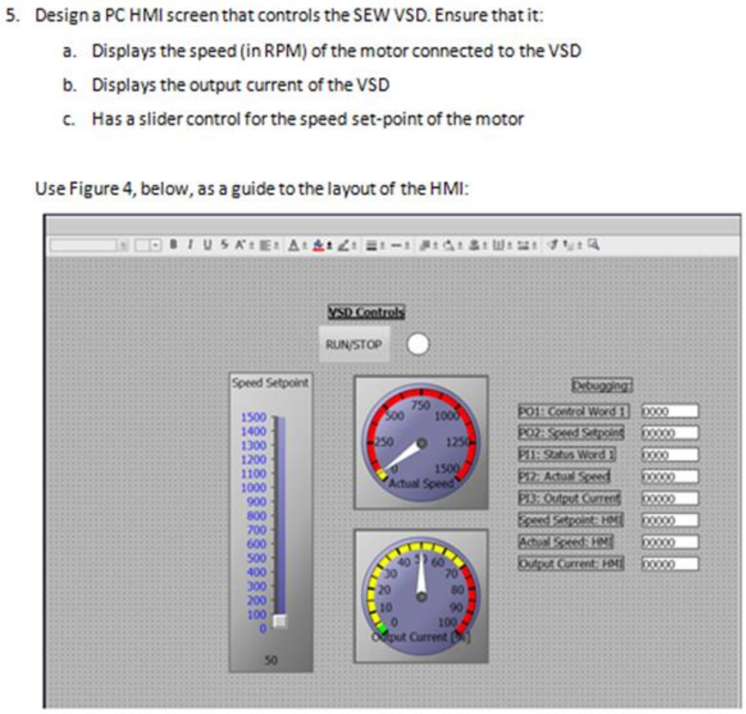
An example of one of these application exercises is taken from the 'WinCC – 1 Panel: Moeller/SEW VSD Screens' learning module. Referring to Figure 18, one of the early exercises in this particular module asks students to setup/configure a PC as a WinCC HMI by referring the students to the 'WinCC Runtime Professional Profibus Configuration Guide' document. This configuration guide walks the students through, step-by-step, to achieving this objective.

3. Follow the steps on pages 1 – 9 of the 'WinCC Runtime Professional Profibus Configuration Guide' document to setup the PC as a WinCC HMI and familiarise yourself with the functions/features of the software detailed in the document.

    a. Pages 1 – 3 describes the steps to configure the PC as a WinCC server
    b. Page 3 onwards describes how to configure the PC as a WinCC HMI, giving users the ability to control/monitor the Profibus network

Figure 18 Question three from the 'WinCC – 1 Panel: Moeller/SEW VSD Screens' Learning Module.

Referring to Figure 19 below, a later exercise in the same learning module asks students to design their own PC HMI screen which controls a VSD. They are detailed the functions that are to be included in the screen and also provided an image which they may choose to use as an example to model the final appearance of their screen on.



5. Design a PC HMI screen that controls the SEW VSD. Ensure that it:
    a. Displays the speed (in RPM) of the motor connected to the VSD
    b. Displays the output current of the VSD
    c. Has a slider control for the speed set-point of the motor

Use Figure 4, below, as a guide to the layout of the HMI:

Figure 19 Question five from the 'WinCC – 1 Panel: Moeller/SEW VSD Screens Learning Modules asks students to develop a PC HMI screen similar to what James Wiggins presented in his thesis report [29].

For this exercise, students are not referred to any configuration manuals – they have already been provided a configuration guide which stepped them through the process of developing HMI screens and they are now expected to use what they have learnt from this earlier exercise from the same module (as well as what they learnt from the earlier 'SEW Eurodrive MOVITRAC B VSD' module) to develop a solution to the lab exercise. This is representative of the style of problem solving they would likely encounter as a professional engineer.

4.2 Methodology

4.2.1 Compile existing material

The first thing to achieve was to locate and store as much previously student-developed learning material as possible. Most of this was sourced from a shared Murdoch University folder titled ENG_Shared and materials gathered by previous students. This folder can be accessed by engineering students via a shortcut on their desktop. Permission to access this folder for other users/readers will need to be arranged through the School of Engineering and Information Technology located in the Science & Computing Building Rm SC2.026 at the South Street Murdoch University Campus.

4.2.2 Learn the Material

Unfortunately most of the learning materials were buried away within folders and subfolders of individual students' and with multiple students having worked on this project previously, it was difficult to decide where to begin.

It was decided that learning would begin using the most recent student's thesis who worked on this project and that was Bilal Ahmad Khan's [22]. After reading through his report primarily, whilst referring to others, a basic understanding of the various technologies was established.

From here work began on learning the configuration manuals produced during some of the phases of the project. Initially, it was hoped that each and every configuration manual could be worked through as if a student was doing so in a lab session however it was soon realised that time would not permit this.

Previous students had spent an entire semester or even year implementing the technologies in a practical setting. Since the main deliverable of this phase of the project was to develop learning modules based on existing student-developed material it was decided that the focus right from the start would be on this – not replicating/reproducing what had been achieved by previous students.

This is not to say the configuration manuals were not studied – every single one was read and studied just not used to implement physical network setups. Since the author had an ICSE background and was able to study the reports of the previous thesis students, following along with the configuration manuals was not overly difficult and a basic understanding of what was being described in each manual could be achieved.

4.2.3 Structure the Learning Modules

Since a basic understanding of all technologies had been established, it was time to plan a structure for the learning modules. The main problem with the existing learning materials was that they were not structured in any formal manner and therefore it was not clear how to progress from one to another.

To address this problem, the work conducted by previous students described in their thesis reports were studied. The latter parts of these reports described what each student actually managed to setup and how they went about doing so. This provided a guide as to how to structure the learning modules.

Most of the work/materials developed had been done on Profibus DP. Additionally, students that utilised numerous technologies always began their projects using Profibus. It was therefore decided that the learning modules would begin with Profibus.

The next step was deciding how the Profibus series of learning modules would progress. It was easy where to start – a fundamental concept of Profibus DP networks is the master-slave relationship where all slave devices connect to a single master which controls all the communications between every slave on the network. All the students who worked on the Profibus side of this project assigned a S7-300 PLC as the master device, primarily because it was the easiest PLC to implement using TIA (automation software) with Moeller Easy PLCs [30] requiring gateways to connect to a Profibus network.

The Profibus learning modules following the Master PLC one involve adding devices one at a time to the network, gradually building it up.

Once the Profibus networks were larger, it was decided to introduce the WinCC SCADA software to teach students how to monitor and control these larger networks effectively.

Half way through the WinCC modules, Profinet is introduced to expose students to a different industrial network standard which they will eventually integrate into their Profibus networks. Please refer to

5.0 Learning Modules

The learning modules discussed in this section will be conducted in Murdoch University's ICSE Laboratory. Each panel in the laboratory will be assigned approximately 3-5 students (depending on class size) who will work together to complete the lab exercises outlined in the modules.

A visual summary of the learning modules and their progressions are shown below in Figure 20 and Figure 21.

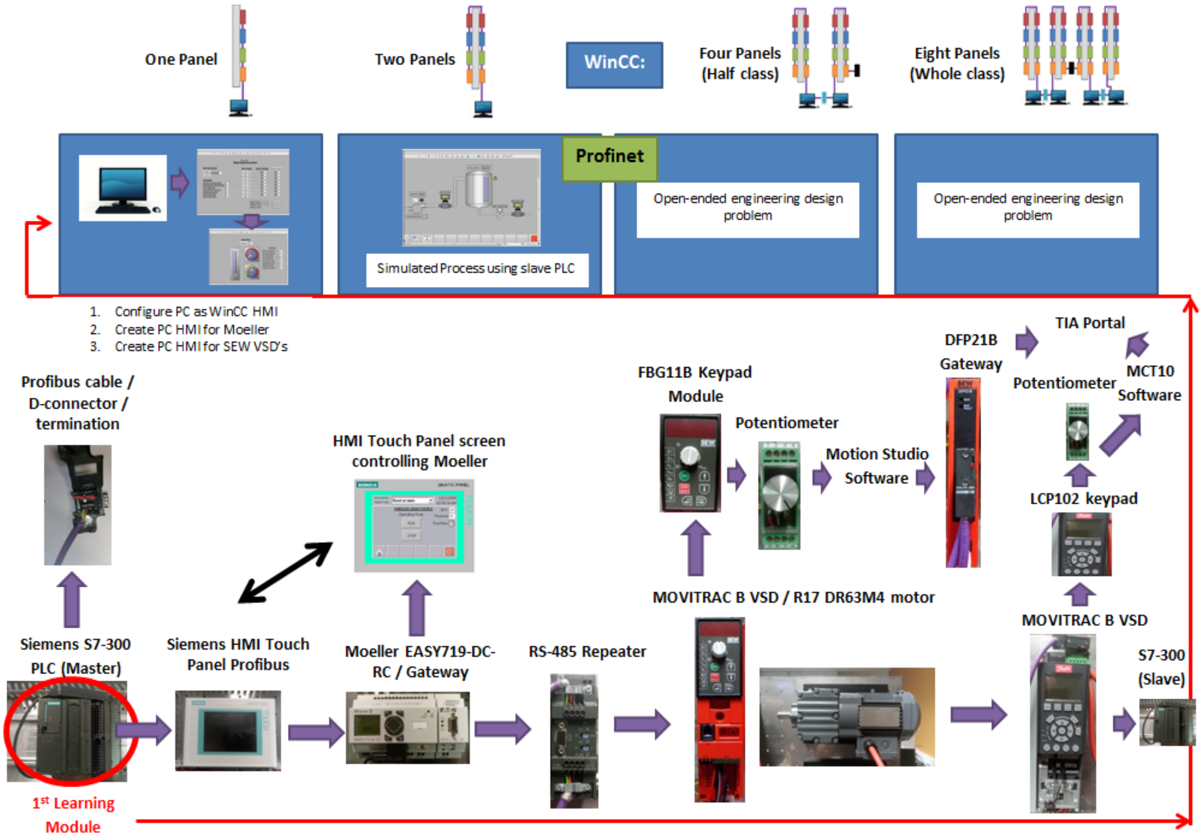


Figure 20 Learning module overall layout and progression

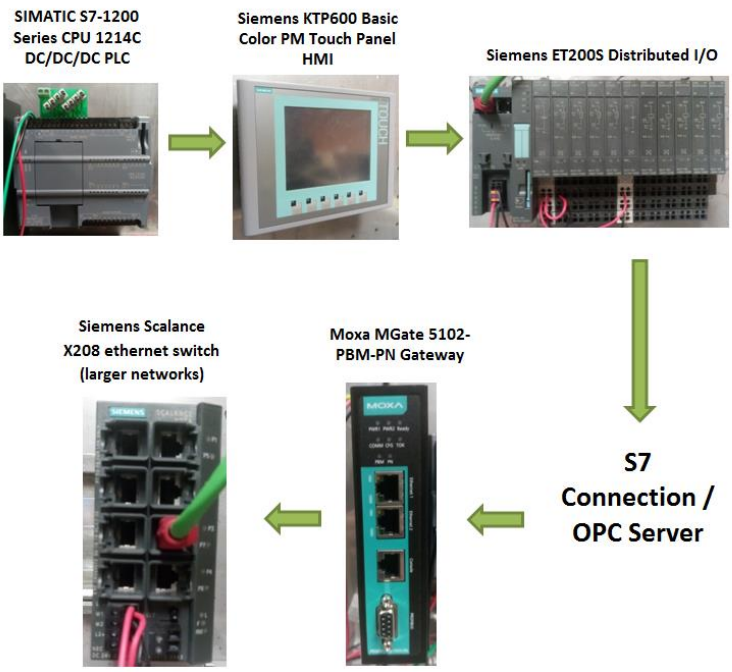


Figure 21 Profinet learning module structure and progression

After being introduced to the theory behind Profibus, students take part in the first practical laboratory session where they set up/configure a Siemens S7-300 PLC as the master device for their industrial network. Students then progress to add various devices to their network as slaves, one module at a time. The end goal of the Profibus series of learning modules is to setup a network similar to that shown in Figure 24.

Throughout the modules, students will use the SIMATIC TIA Step 7 Professional V13 software [23] developed by Siemens to configure their networks/devices and to develop PLC programs. SIMATIC is a term that refers to all of Siemens automation products while TIA is a platform for fostering multi-vendor interoperability of devices and components. Step 7 is the central automation tool that integrates into TIA.

Students have used Step 7 in previous units and are therefore familiar with the software and its workflow, facilitating fasting learning progression in ENG448. All the PCs in the ICSE Laboratory have this software installed and configured.

From here on in the report, this software package will simply be referred to as 'TIA'.

5.1 Profibus

It was decided to begin the learning modules with the industrial network protocol Profibus.

Of the two protocols taught in ENG448 Profibus is the older of the two technologies (with the other being Profinet) and is simpler from a technical point of view. It utilises the RS-485 OSI model physical layer which is one of the simplest (and often most effective) network standards used in industrial settings.

ICSE students have background knowledge and experience in using RS-485. They were introduced to the standard in the ENG321 unit from both theoretical and practical perspectives. They have a sound understanding of how RS-485 works and have used this technology to communicate between different devices.

This foundation of knowledge and previous exposure to the relatively simple network standard of RS-485 makes Profibus an excellent starting point for students in ENG448 and will allow them to setup Profibus networks consisting of devices they have also been exposed to in previous units, as well as new ones.

5.1.1 Introduction

In the Profibus series of learning modules students work towards building and configuring their first Profibus network consisting of numerous devices on a single ICSE Lab panel as shown below in Figure 22.

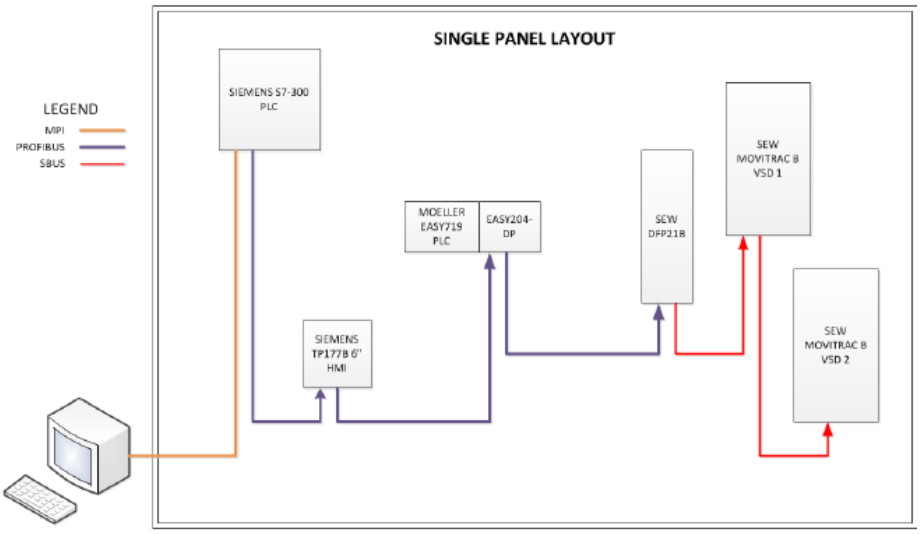


Figure 22 ICSE Lab single panel Profibus network [29]

After achieving this, the network is expanded to utilise two ICSE Lab panels as shown in Figure 23 and Figure 24.

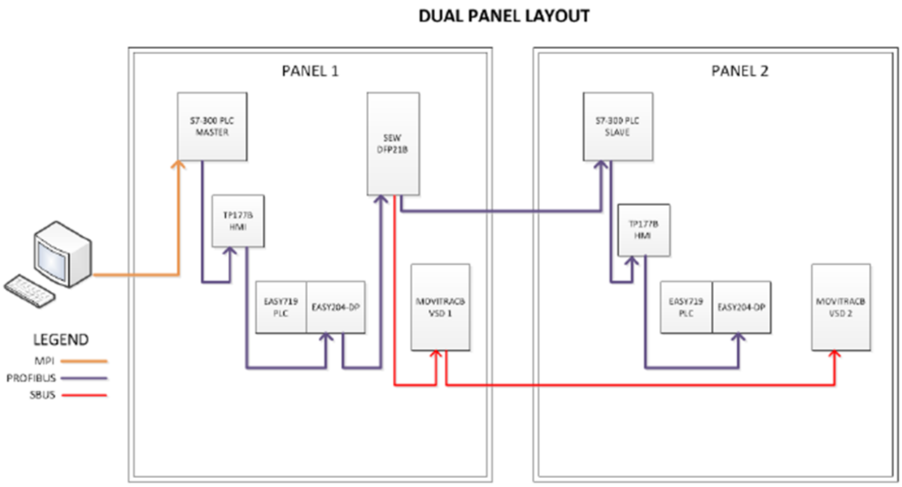


Figure 23 ICSE Lab dual panel Profibus network [29]

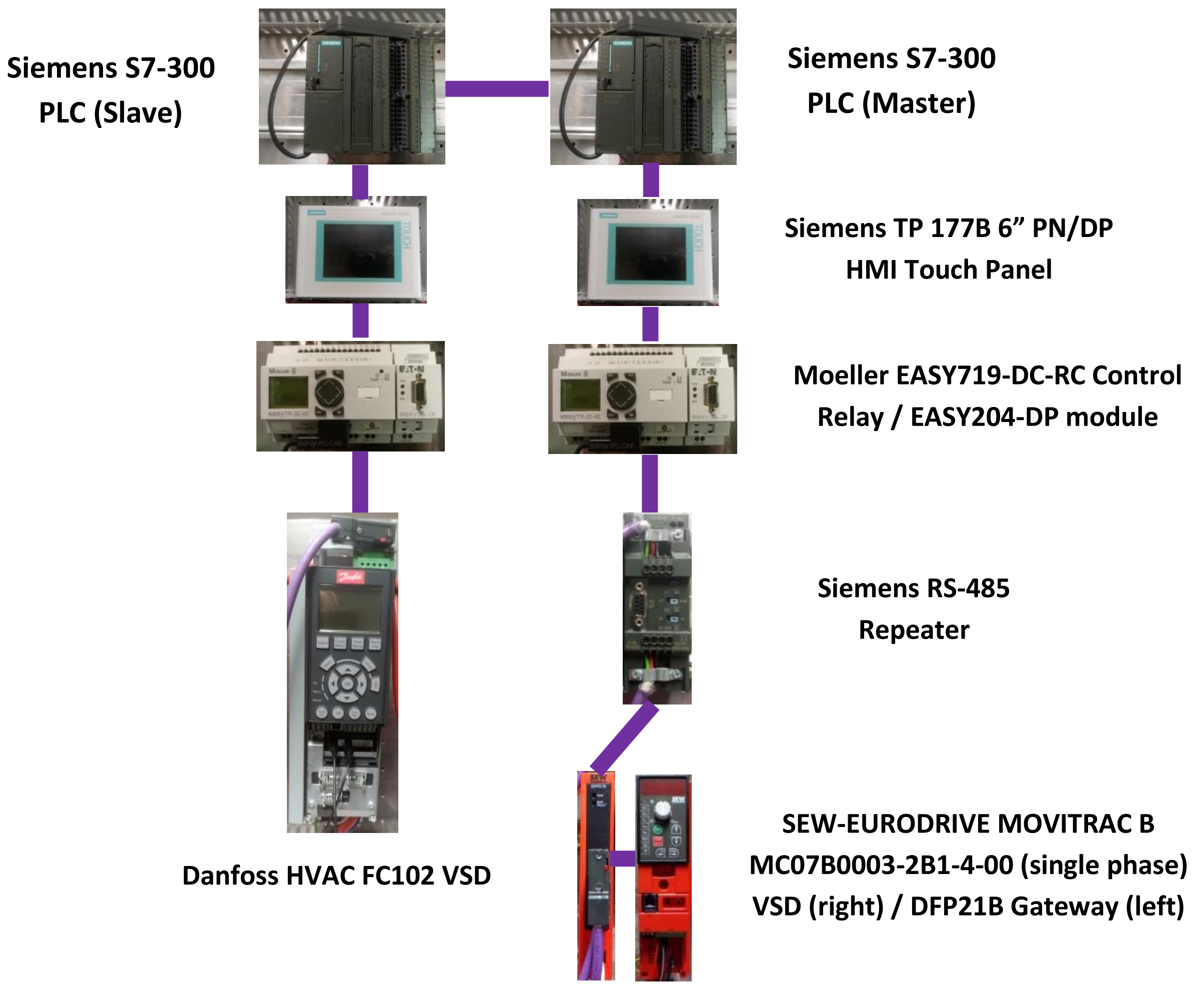


Figure 24 ICSE Lab dual panel Profibus network with device images, based on [75]

This introduction module introduces students to Profibus by referring them to various learning materials including previous thesis reports and YouTube videos. By providing students with extensive introductory learning materials, they will be better prepared and more confident for the practical learning modules ahead.

5.1.2 S7-300 PLC

The first practical learning module students will undertake is the S7-300 PLC module. PLCs are industrial computers that are designed to operate in harsh environments like those with extreme temperatures, vibrations and wet or dusty conditions. They are also designed to be extremely reliable and operated for extended (often indefinite) periods of time. These characteristics make them well-suited to monitor and control industrial processes such as production lines and robotic devices [31].

PLCs operate by continuously monitoring the state of their inputs (often sensors) and through custom user-developed program/s control the state of their outputs and subsequent connected devices [31].

Students have previously been exposed to numerous PLCs in the ENG311 unit where they learnt how to use these devices for computer-based measurement and control in an industrial process setting. Since students have had experience in using PLCs in a standalone nature, the emphasis for ENG448 is using these devices in larger networks and communicating between them and other devices on such networks, not on developing overly-complicated PLC programs.

The S7-300 PLC with the 314C-2 DP [32] type central processing unit (CPU) is a small modular PLC manufactured by Siemens with a low to medium performance range. Students used this particular PLC extensively in ENG311 so they are very familiar with its features and functionality.

This particular learning module sees students connect to this PLC via both multi-point interface (MPI) and Profibus DP protocols. Following James Wiggin's 'Siemens S7-300 PLC & RS-485 Repeater Profibus Configuration Guide', students configure the PLC as the master device of the Profibus network which all other devices in the subsequent learning modules will connect to as slaves. This concept is very important because the primary form of MAC used for the Profibus protocol is a master-slave configuration where the master device controls the communication between all connected slave devices. This is also why the first practical Profibus learning module uses the S7-300 PLC – this master device forms the foundation of the Profibus network, which students will expand by connecting various other devices to as 'intelligent slaves'. Students set up this network using Siemen's SIMATIC TIA Step 7 Professional V13.

Since this is the first time students will have used Profibus DP cables and connectors, they are given the chance to set up the network from scratch from a hardware point of view. This involves cutting/stripping Profibus cable and attaching them to Profibus DP connectors as shown below in Figure 25. Since this process is timely and also resource intensive with lots of cable being used, it is restricted to this single learning module. This is to ensure that Murdoch University does not run out of either Profibus cables or connectors which are costly to purchase on an ongoing basis. For future modules, students will simply use existing Profibus cables which have been pre-cut and attached to connectors. This will also save time and allow students to progress their learning faster rather than needing to constantly cut/strip cables for every learning module.

Figure 25 Students learn how to strip and attach Profibus DP cables to Profibus DP connectors and subsequently how to terminate networks using termination switches [29].

After configuring the S7-300 PLC as a master device on the Profibus network, each group will then team up with the group on the opposite side of their panel and connect one of the

S7-300s to the master S7-300 as a slave, illustrated in Figure 26, by following James Wiggin's 'Siemens S7-300 PLC & RS-485 Repeater Profibus Configuration Guide' [33].

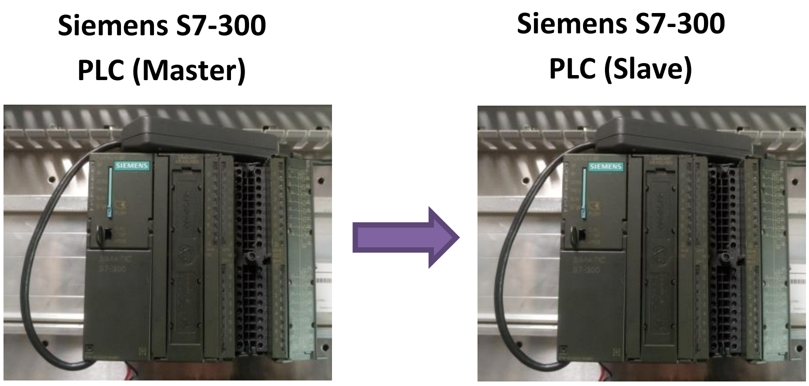


Figure 26 S7-300 module master-slave network structure

Once the two PLCs are connected, students will develop TIA programs that exchange data between the two following the Profibus DP report [34] which is adapted from Brenton Walker's thesis [7]. The main important concept addressed in this part of the module is:

1. reading data from the physical input of PLC1,
2. storing this data in the PLC's memory and,
3. transferring this data over the Profibus Subnet created when configuring the PLCs in TIA Portal to PLC2.

Items one and two were covered extensively in ENG311. Item three however forms the foundation of all later modules for ENG448 as one of the key areas focused on is data transfer over industrial networks.

5.1.3 Siemens HMI Touch Panel

In this learning module, students connect a Siemens TP 177B 6" PN/DP HMI Touch Panel [35], shown in Figure 27 as a slave device to a Master Siemens S7-300 PLC. HMI stands for human machine interface. This is an important module because students learn how to monitor and control network elements via the HMI which is similar to what they will do in the later WinCC learning modules. Students have had exposure to HMIs in ENG311 however this was only brief and did not involve the use of them in industrial networks, only PLCs.

Figure 27 Siemens TP 177B 6” PN/DP HMI Touch Panel

HMIs, as the name implies, are devices that act as interfaces between operators (humans) and the machines/devices in the field. Typically a HMI is assigned to a single device and can be located closer to the device than the central control room.

Monitoring of whole or parts of processes is made easier by user programmed images and graphics that present the data in a more intuitive manner.

As well as monitoring, control of processes can be achieved by user interaction with the HMI, often in the form of touch screens and buttons. The way this is achieved is by having these user interactions assigned to memory ‘tags’ within the HMI that are linked to the connected controller (often a PLC). The data is constantly transferred between controller and HMI in real time. A memory ‘tag’ is simply a specific memory location that is stored inside the controlling PLC.

These devices can also be setup with user authentication where users are only granted control of the parameters that they are permitted to access/control [35].

Whilst monitoring of current values is important, HMIs allow for the display of historic values in the form of ‘trending’. This could be in the form of a graph or table and is achieved by accessing values which are stored in a database. Alarms can also be programmed to trigger for certain events such as reaching minimum/maximum values. All this data can then be logged and exported.

The key features of the Siemens TP 177B 6" PN/DP HMI touch panel used in this learning module are a:

- six inch display/touch screen for operator interaction
- 9-pin female D connector located underneath the unit for physical connection onto the Profibus network
- DIP switches located on the rear of the unit for assigning a unique Profibus address to the device

In the learning module, students first install the hardware and then configure the software of the HMI. Following this they learn how to program the HMI and develop 'screens' which will be displayed on the unit. These items are explained in James Wiggin's 'Siemens HMI Touch Panel Profibus Configuration Guide' document. Students are then asked to create/test a screen that monitors and controls the inputs and outputs of the connected S7-300 PLC.

5.1.4 Moeller EASY719-DC-RC Control Relay

The Moeller EASY719 DC-RC Control Relay (EASY719) [30] is actually a PLC. Although it shares similarities in terms of the functions to the Siemens S7-300 PLC, it is a much simpler controller with more restricted capabilities compared to the Siemens. Students were also exposed to this PLC in ENG311 much like the S7-300 but once again only from a PLC programming perspective, not a network integration perspective.

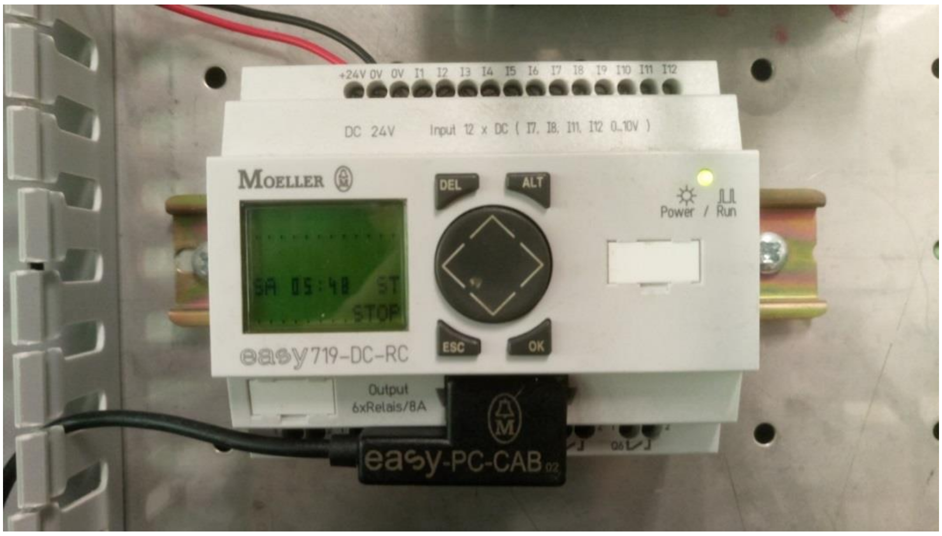


Figure 28 Moeller EASY719-DC-RC Control Relay

The EASY719 features an LCD screen used for displaying the functions and status of the controller as well as buttons for configuration of these. It is unique in the sense that it can be programmed without the need for a computer (although it does include ladder-logic style software for easier programming via a computer).

The EASY719 was actually not initially developed for Profibus-DP communication which means that a key piece of technology is introduced in this module. This is the ‘gateway’ [30]. A gateway is a device that connects two different networks with different protocols by interfacing between the two and translating the two different network protocols. A gateway serves the same purpose as a spoken language translator.

Referring to Figure 29 below, if say a English-speaking person A is talking to an Japanese-speaking person B the translator will facilitate the dialogue between the two people by translating back and forth between the two languages. A gateway serves this exact purpose albeit in a computer network context rather than spoken language one.

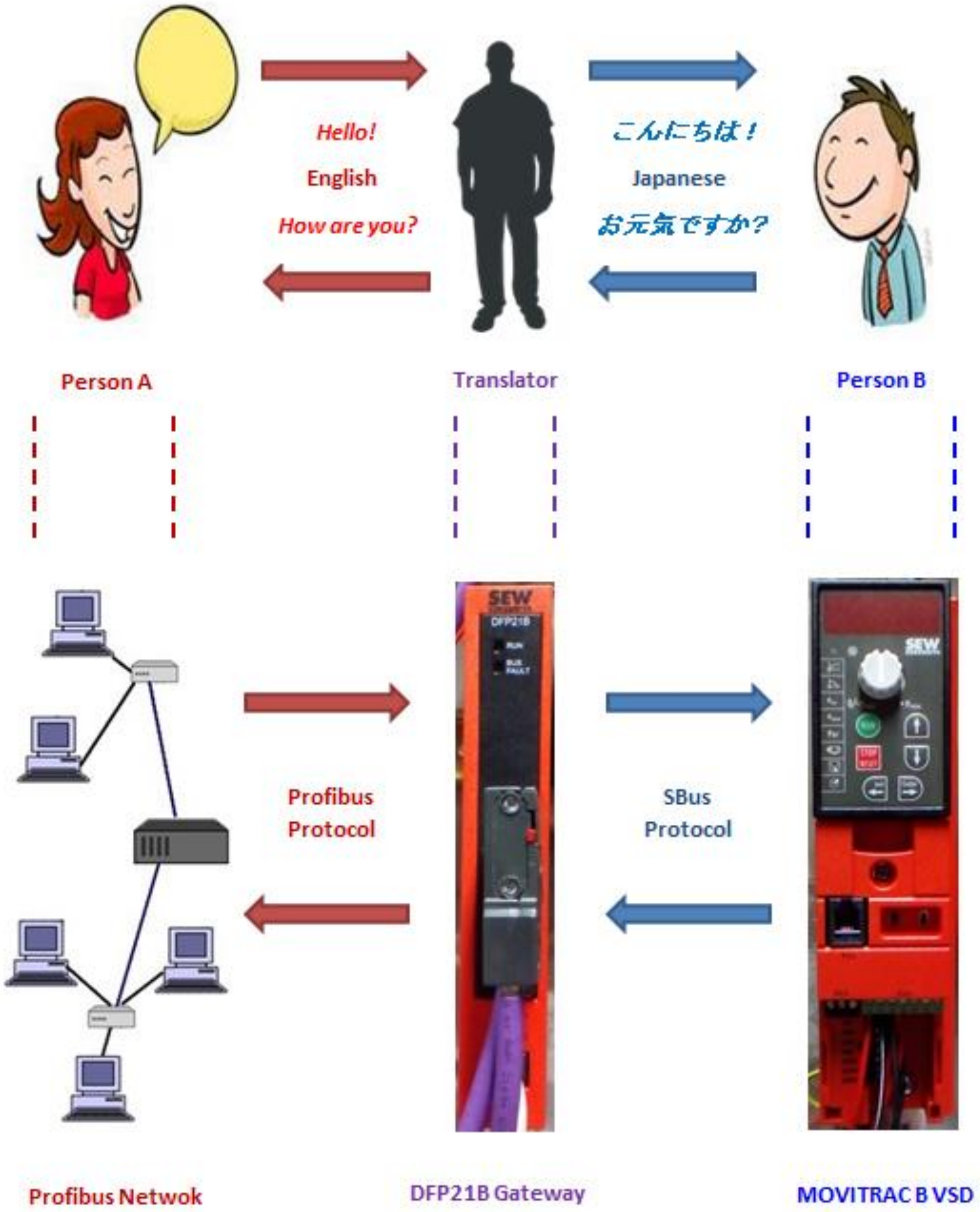


Figure 29 Illustration of the function of a network gateway

The particular gateway used to interface between the EASY719 and Profibus network is in the form of an expansion unit called a Moeller EASY204-DP Profibus-DP [36] slave gateway (EASY204-DP), pictured below in Figure 30.

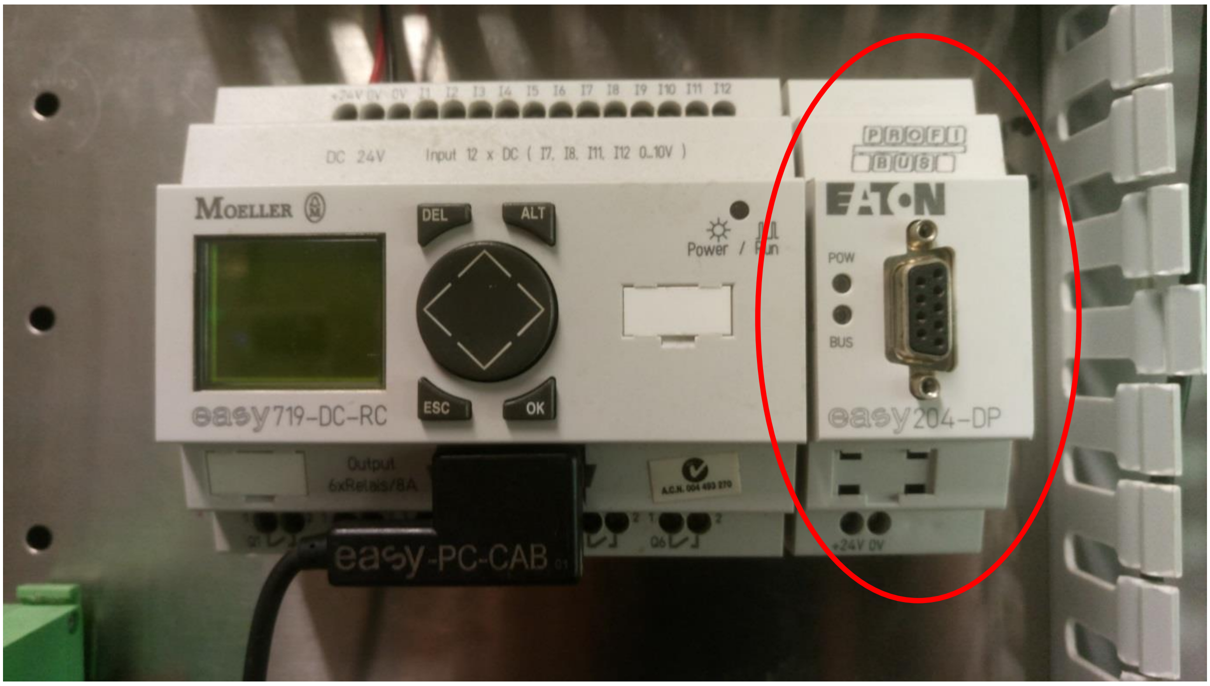
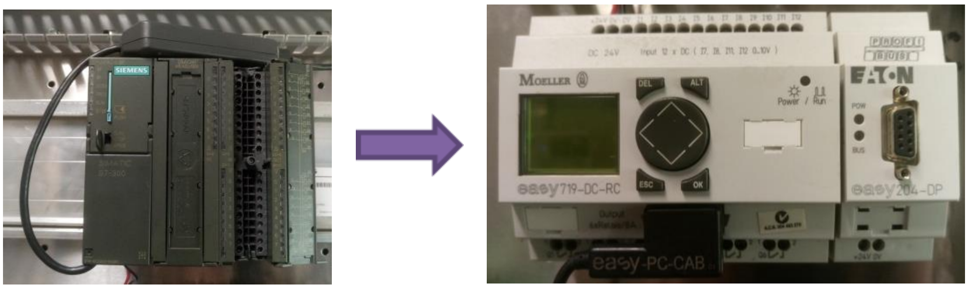


Figure 30 EASY204-DP module attached to Moeller EASY719-DC-RC Control Relay

With the EASY204-DP comes another important concept in the context of the ENG448 unit which is introduced in this module. That is a General Station Description (GSD) file [36]. GSD files are required for every device connected to a Profibus network. They are created by the specific device manufacturer to assist with the configuration of the device. These files contain parameter and configuration data like: transmission speed, data length, address allocation, I/O data and bus parameters. The connected Profibus master device uses this data to configure the device automatically at device start-up ensuring correct transmission and data procedures. GSD files will either come shipped with the device or can be downloaded from their manufacturer's website.

In the laboratory for this learning module, students first setup the EASY204-DP hardware by following James Wiggin's 'Moeller EASY719 Control Relay Profibus Configuration Guide' document [37]. The control relay is first connected directly to the S7-300 PLC, shown below in Figure 31, to allow students to become familiar with communicating with the relay in a two-device network before expanding the network developed in the previous learning module. The control relay is then configured as a slave in TIA Portal with the Profibus subnet and subsequent transfer areas created.



Siemens S7-300 Master PLC

Moeller EASY719-DC-RC Control Relay / EASY204-DP module

Figure 31 Students first connect the EASY719 directly to the S7-300

Now that the master S7-300 PLC and slave EASY719 are ready to communicate, students develop programs that exchange data between the two devices following the Profibus DP [38] document which was based around work conducted by Brenton Walker [7]. This follows the same principles introduced in the S7-300 learning module where two S7-300 PLC's transfer data however there a slight variations in the configuration and subsequent programs developed to allow the EASY719 to communicate. After students have successfully communicated between the two devices, the network is expanded to include the Siemens HMI, shown below in Figure 32 which was used in the previous learning module.

Siemens S7-300 Master PLC

Siemens TP 177B 6" PN/DP HMI Touch Panel

Moeller EASY719-DC-RC Control Relay / EASY204-DP module

Figure 32 An expanded network utilising three devices

This is a considerable milestone in the unit because it is the first time students have configured two slaves in the single network. This will form the basis knowledge in all later learning modules where students expand their networks further.

To utilise the HMI, students are asked to develop a HMI program that consists of two screens which can both monitor and control the various inputs/outputs of the EASY719 (similar to that shown below in Figure 33 and Figure 34. Students are provided with two images of example screens developed by James Wiggins [29] during his thesis to assist the students in understanding what needs to be achieved with the HMI screens.

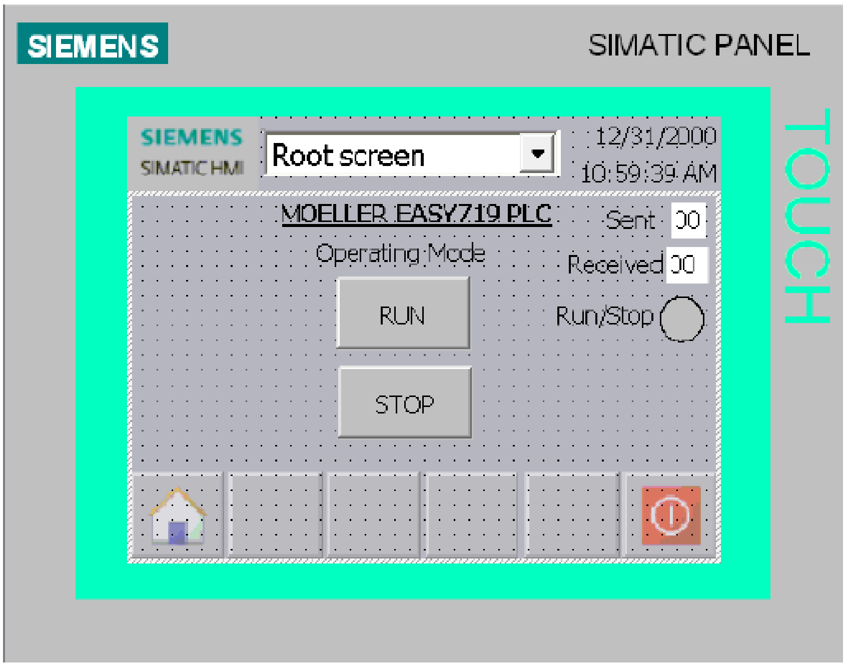


Figure 33 The first example HMI screen for monitoring and controlling the EASY719 [29]

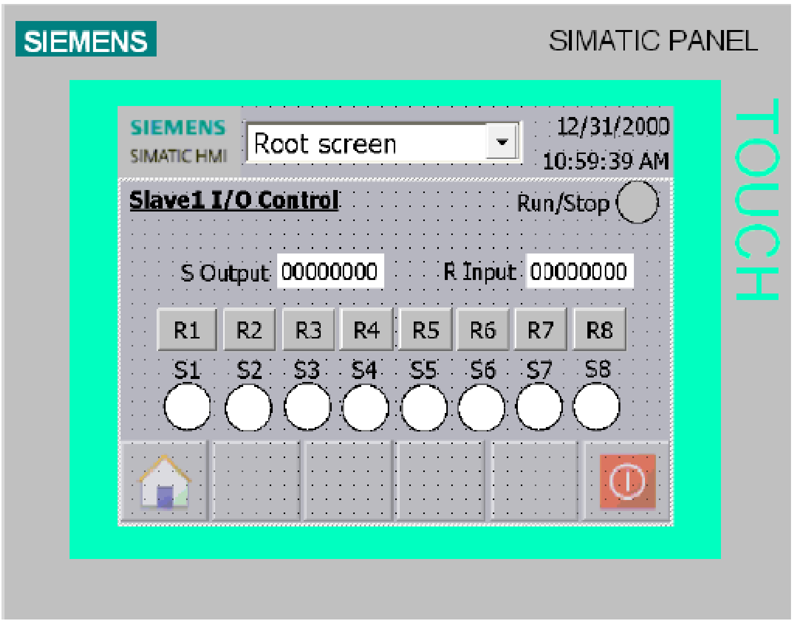


Figure 34 The second example HMI screen for monitoring and controlling the EASY719 [29]

This concept of using a HMI to monitor and control elements in a network is a major part of the unit, particularly during the later WinCC learning modules where students will develop HMIs for PC screens rather than the Siemens Touch Panel HMI. It is important students become confident in developing screens for the Siemen's HMI as doing so in a WinCC context is more complicated.

5.1.5 RS-485 Repeater

This module is considered to be optional depending on whether the unit coordinator intends students to integrate repeaters into their networks or not.

Repeaters are used in Profibus network for one or more of the following three reasons (illustrated in Figure 35) [22] [7]:

- Increasing the length of the network
  - This is achieved by amplifying the bus data signals, specifically, their amplitude, edge slope and signal width.
- Increasing the number of devices connected to the network
  - Without repeaters, a maximum of 32 devices can be connected to a single network. With repeaters, up to 128 devices can be connected. Each additional repeater increases to device limit by 31.
  - A maximum of 9 repeaters may be connected in series.
- Network segmentation
  - Segmentation allows an extra 'branch' to be added to a Profibus network rather than having a single linear bus line. This has the potential benefit of reducing the amount of cable used in complex networks. However for the scope of this unit, it is unlikely that students would need to use a repeater for this specific purpose.
  - Segmentation can make troubleshooting/isolating networks easier with the ability to terminate bus sections at the repeater.

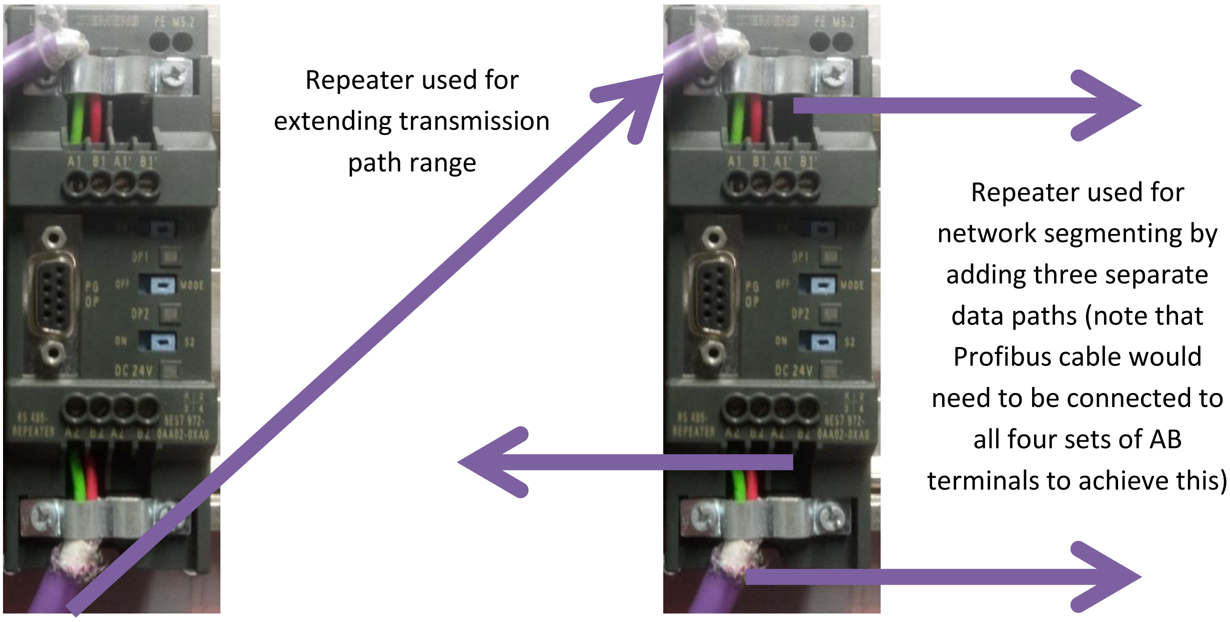


Figure 35 Illustration of repeater length extension and network segmentation, based on [7]

The Siemens RS-485 Repeater, model number 6ES7972-0AA02-0XA0 [39] is used in this unit and is pictured below in Figure 36.

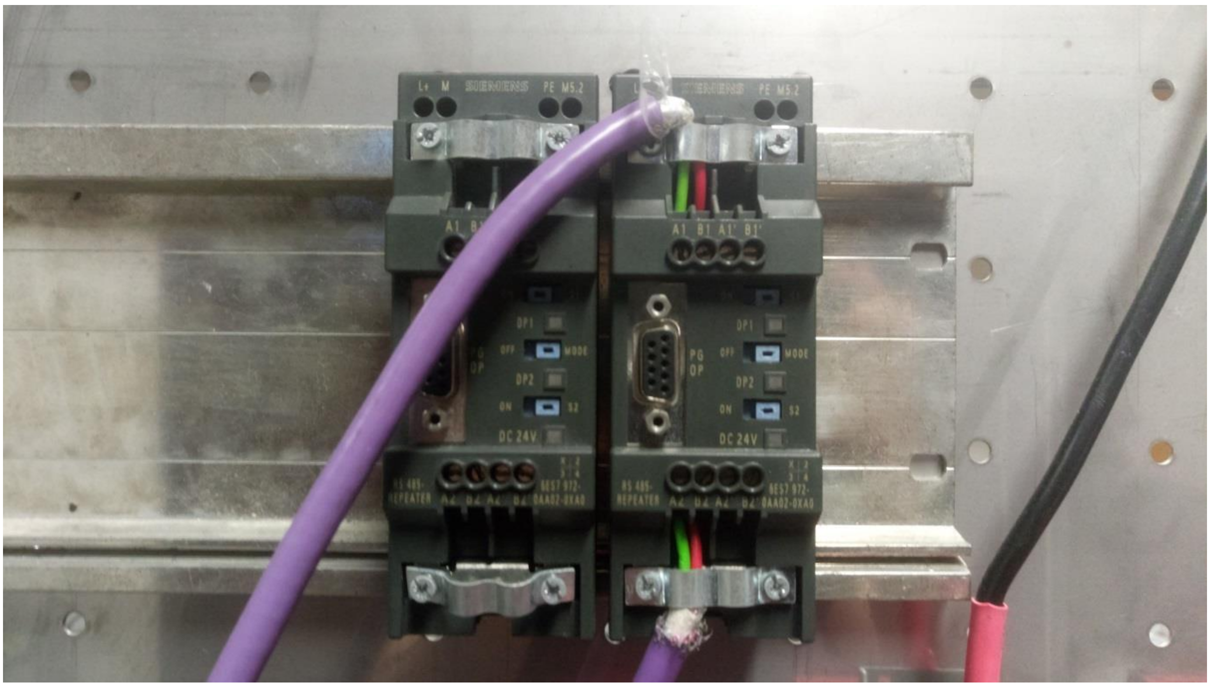


Figure 36 Two Siemens RS-485 Repeaters, the right with connected Profibus cables

Configuring the repeater is straight forward due to its 'plug and play' ability. There is no need for software changes in the TIA Portal. This module simply involves connecting segments to the repeater and using its termination functions to isolate these. This module will allow students to utilise repeaters in designs of more complex networks in later modules.

5.1.6 SEW Eurodrive MOVITRAC B VSD

This module introduces students to new hardware that they have not previously been exposed to – variable speed drives (VSDs). VSDs are devices that regulate the speed and torque (rotation force) output of an electric motor. Motors can be controlled without VSDs by the following methods [40]:

1. A valve that regulates the flow of fuel or a vane controlling airflow into the motor
2. The use of two-speed motors
3. Periodic on-off switching

The downside to these methods, however, is that they are not energy efficient. With over 65% of industrial electrical energy being consumed by motors [40], VSDs have the potential to save large amounts of energy and subsequent costs.

VSDs control the speed of an electric motor by controlling the amount of power fed in [40].

There are three main types of VSD [41]:

- variable voltages inverter (VVI) ,
- current source inverter (CSI) and,
- pulse width modulator (PWM) inverter.

Referring to Figure 37, all three VSD types consist of [41] :

- either an AC to DC rectifier or converter to convert the input three-phase power supply to DC power and controls the input voltage if it is variable
- a DC link for either voltage or current smoothing and,
- a DC to AC inverter to control the output rotation frequency or both frequency and voltage, depending on the VSD type.

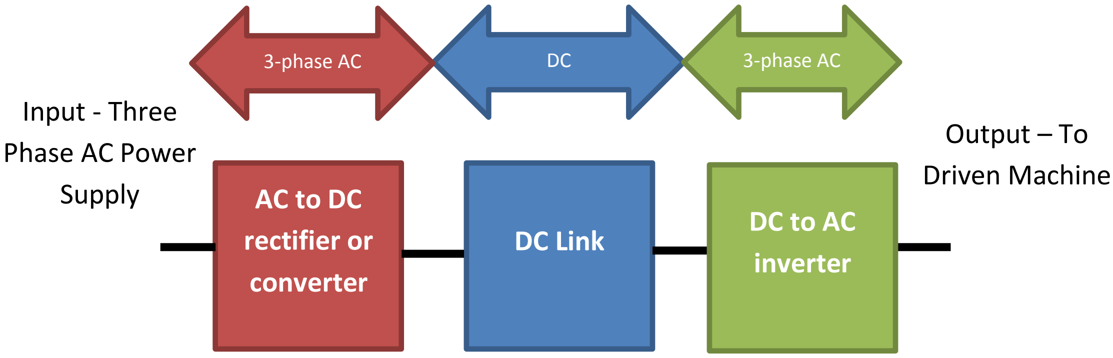


Figure 37 VSD internals flow chart for a PWM, based on [41]

Due to the importance and widespread use of VSDs Murdoch University procured two types of VSDs for use in ENG448.

The first which is introduced in this module is the MOVITRAC B series of VSDs manufactured by SEW-EURODRIVE pictured below in Figure 38.

Figure 38 SEW-EURODRIVE MOVITRAC B MC07B0003-2B1-4-00 (single phase) VSD (left) and DFP21B Gateway (right)

The MOVITRAC B range of VDSs are designed to comply with industry regulations including:

- Low Voltage Directive 2006/95/EC [42]
- EMC (electromagnetic compatibility) product standards EN61800-3 *Variable-speed electrical drives* [43]

The specific model of the SEW-EURODRIVE MOVITRAC B VSD (SEW VSD) is the **MC07B0003-2B1-4-00** (single phase) which has the following specifications (shown below in Table 4):

Table 4 MOVITRAC B VSD Specifications, data obtained from [22]

Properties	Description / Range
Voltage Range	AC 200 – 240 V , 50/60 Hz
Speed Range	0-5500 rpm
Ambient Temp	-10 to 50 °C
Output Power	0.25 KW / 0.34 HP
Power Loss 100 % Operation	30 W

The SEW VSD will be used to drive a SEW-EURODRIVE R Series R17 DR63M4 model foot-mounted, multi-stage helical motor (hereon referred to as R17) [44] pictured below in Figure 39. There will be one VSD/motor setup per panel in the ICSE Lab Room.

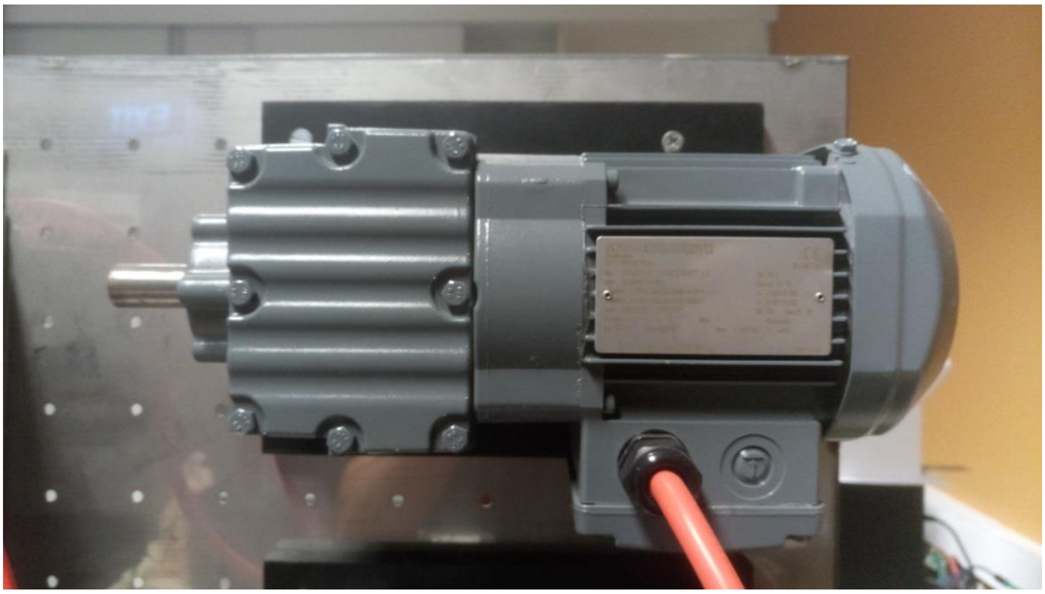


Figure 39 SEW-EURODRIVE R Series R17 DR63M4 Motor

After setting up the VSD, students first learn how to control the VSD via the FBG11B Keypad Module located on the front of the SEW VSD unit. It was decided to have students control the motor using this method first as it is the easiest method and introduces students to the physical controls on the unit. They achieve this by following the steps in James Wiggin's 'SEW Eurodrive MOVITRAC B VSD Profibus Configuration Guide' [45] whilst referring to Xu's [21] and Khan's [22] thesis'.

Once control the FBG11B Keypad has been achieved students follow the steps in Hao Xu's thesis [21] to control the motor via a potentiometer. Potentiometers are variable resistors that change resistance depending on the position of a rotatable knob. Students have used potentiometers extensively to control systems using this analogue approach.

Next, students are introduced to the SEW MOVITOOLS-MotionStudio software [46]. This proprietary software allows for more advanced control/configuration of the SEW VSD. Software tend to have relatively steep learning curves so it is hoped the documentation [45] will facilitate fast learning of the software's features and functions.

The next section of the lab will involve using a DFP21B Gateway [47], pictured in Figure 38. Similar to the EASY204-DP Gateway used in the 'Moeller EASY-DC-RC Control Relay' learning module, this gateway will be used to connect the SEW VSD to a Profibus network. It does this by interfacing with a FSC11B Communication Module [48] which is connected to the VSD and communicates to it via SEW's proprietary 'Sbus' protocol [24]. For a visual representation of what the gateway does, see Figure 29.

Referring to Figure 40, students will first connect the gateway to the communication module by wiring the correct terminals on each module. They will then assign a unique Profibus address to the gateway via its DIP switches located on the front of the unit and configure the connection to the Profibus network in the TIA Portal. The gateway will not be directly connected to the Master S7-300 PLC but will rather be added onto the network developed in the previous learning module.

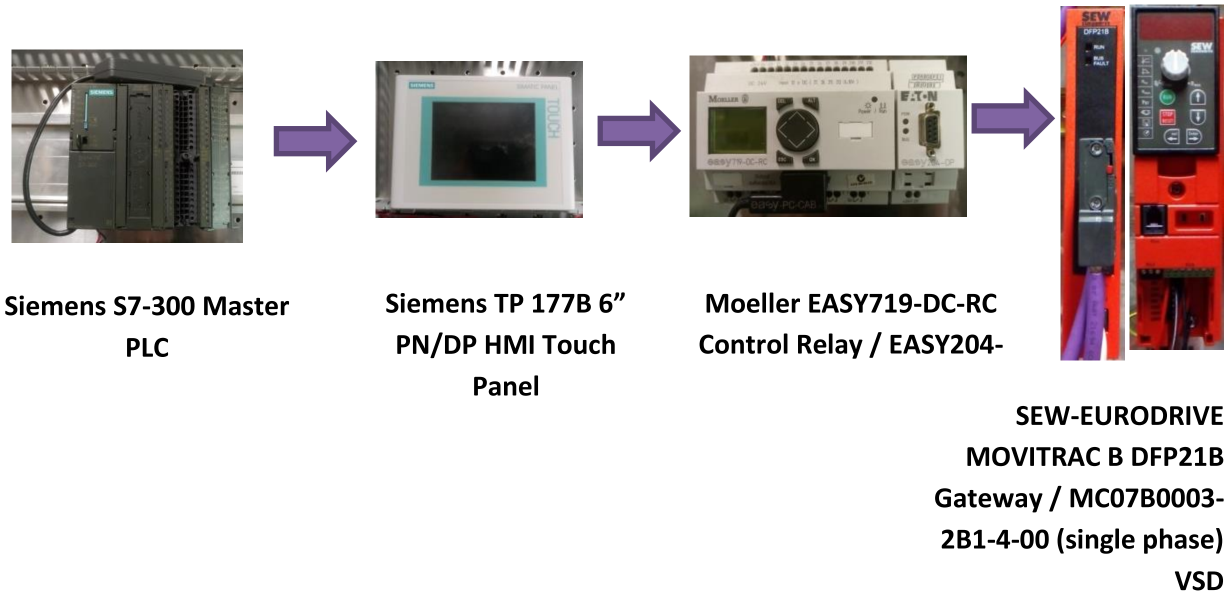


Figure 40 Network bus structure of the SEW Eurodrive MOVITRAC B VSD Learning Module

Finally, communication will be established between the VSD and Master S7-300 PLC via programs developed on the controller.

To summarise, students will learn how to control a SEW VSD via the:

i. FBG11 Keypad

ii. SEW MOVITOOLS-MotionStudio software

iii. S7-300 Master PLC.

5.1.7 Danfoss VSD

A second VSD will be introduced in ENG448, namely, the HVAC FC102 VSD [49] manufactured by Danfoss (Danfoss VSD), pictured below in Figure 41. It fully complies with EMC standards [50]. The Danfoss VSD features an integrated scalable Radio Frequency Interference Filter (RFI) which minimises electromagnetic interference. A DC link is also used to reduce harmonic distortion from the mains power supply. As well as basic VSD functionality, it can perform logical operations and complex control functions including cascaded control [49]. The Danfoss VSD is typically used to drive evaporators, pumps, compressors, condensers and fans.

Figure 41 Danfoss HVAC FC102 VSD

This VSD is quite different to the SEW VSD introduced in the previous module because it requires three-phase power to operate. There is only one three-phase power socket in the ICSE Lab Room, so this module will therefore be conducted by one group (panel) at a time.

Since students are not permitted to access three-phase power, the VSD as well as the three phase motor it will be powering, a SA5 R17 DR63S4 manufactured by SEW Eurodrive will be setup by the technicians ahead of the laboratory session. This learning module follows a similar structure to that of the SEW VSD learning module:

1. Students first learn how to control the VSD via its LCP102 Keypad, including ramping speeds up and down.
2. Then speed control via an externally wired potentiometer is setup.
3. Danfoss proprietary MCT10 Configuration Platform software will be used to control the VSD and explore more advanced functionality.

4. The VSD will be connected to a Profibus network via a MCA 101 Profibus Gateway Adapter. The network will only consist of a master S7-300 PLC controller
5. Read/write programs will be developed in the TIA Portal for communication and control via the Master S7-300 PLC.

5.1.8 Siemens S7-300 PLC (Slave)

In the final Profibus learning module, students will utilise two panels and set up the network shown in Figure 24. This is the final network that students have been working towards and will involve all the devices so far learnt in ENG448.

5.2 SIMATIC WinCC Realtime Professional

The first series of learning modules in ENG448 address items 1 and 2 in section 3.4.2 by introducing the industrial communications networking standard of Profibus. In these modules students develop networks where various devices communicate over them. As the networks become larger, it soon becomes clear that monitoring and controlling elements within these becomes cumbersome. Even though HMIs are used to control specific devices, they are not typically used to monitor/control multiple devices and sections of networks.

To make such monitoring/control of larger industrial networks possible, SCADA software is introduced to students in the form of SIMATIC WinCC Runtime Professional (WinCC) produced by Siemens. This software has all the major features of a SCADA software system discussed in section 3.4 It is a scalable process-visualisation supervisory control and data acquisition (SCADA) system produced by Siemens for monitoring automated processes.

WinCC therefore fulfils points 3 and 4 of section 3.4.2 by providing a platform for configuring computers as SCADA central host computers and subsequent development of operator workstations where plant data can be presented in useable formats.

This section briefly summarises and discusses the WinCC learning modules developed for ENG448. In these modules, students will use WinCC to monitor/control devices on individual panels as well as multiple panels. Students will even learn how to do so for all eight panel in the ICSE Laboratory at once, simulating a real world plant with many different devices.

5.2.1 One Panel – Moeller + VSD HMIs

In the first WinCC learning module, students will work to develop a SCADA system for a single panel in the ICSE Lab Room.

They will first set up the hardware on their panel in the configuration shown below in Figure 42. One difference with this setup is that students will need to use their panels corresponding PC on the entry/exit side of the room. This is because the four computers located on this side of the room have the required CP5611 [51] installed to connect to the network's master device via Profibus (MPI cannot be used for SCADA). Since there are only four of these computers, each group will have to team up with the group on the opposite side of their panel.

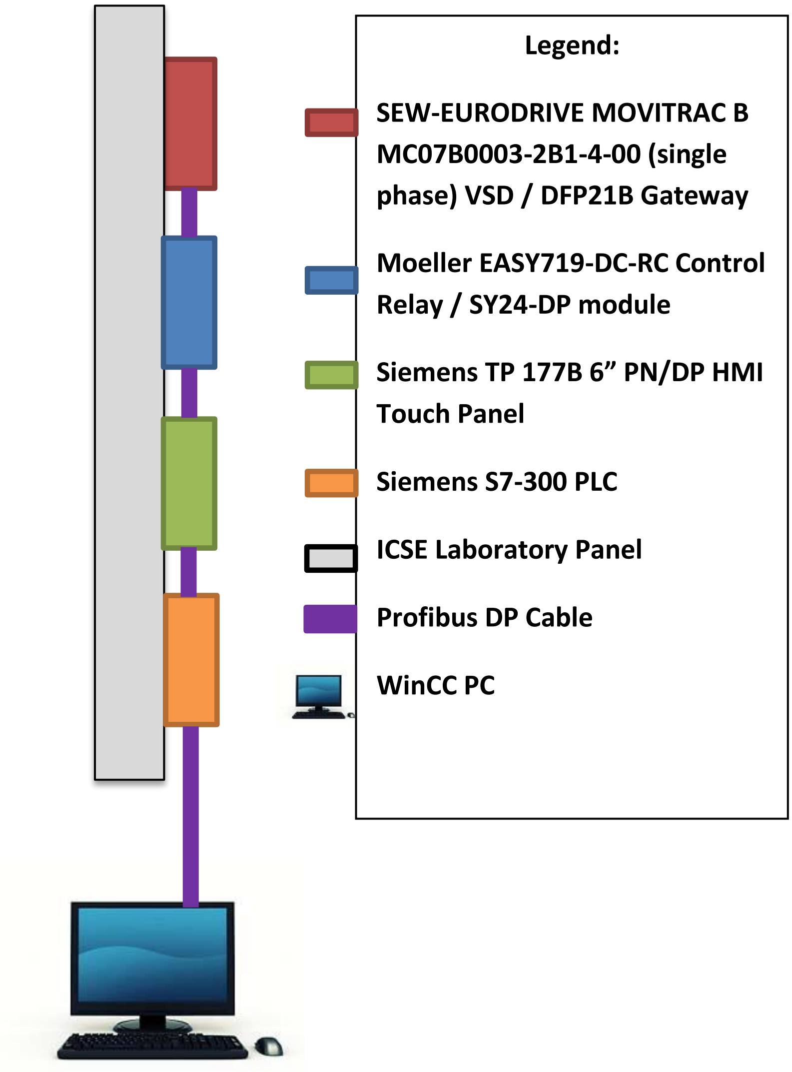


Figure 42 Single panel WinCC layout, based on [53]

After the Profibus network has been setup using the skills developed in the previous Profibus series of learning modules students will follow the steps in James Wiggin's 'WinCC Runtime Professional Profibus Configuration Guide' [52] to configure the PC as a WinCC server which will also double as a HMI. Once again, this will be done through the TIA Portal which WinCC integrates into.

Once the PC has been configured, students will be asked to develop a HMI screen, similar to the one they developed in the earlier 'Easy Moeller' Profibus learning module that monitors/controls the various inputs and outputs of the EASY719 control relay remotely on the WinCC PC. An example image, shown below in Figure 43, will be provided to indicate how their developed may look. This particular screen was developed by James Wiggins during his thesis project.

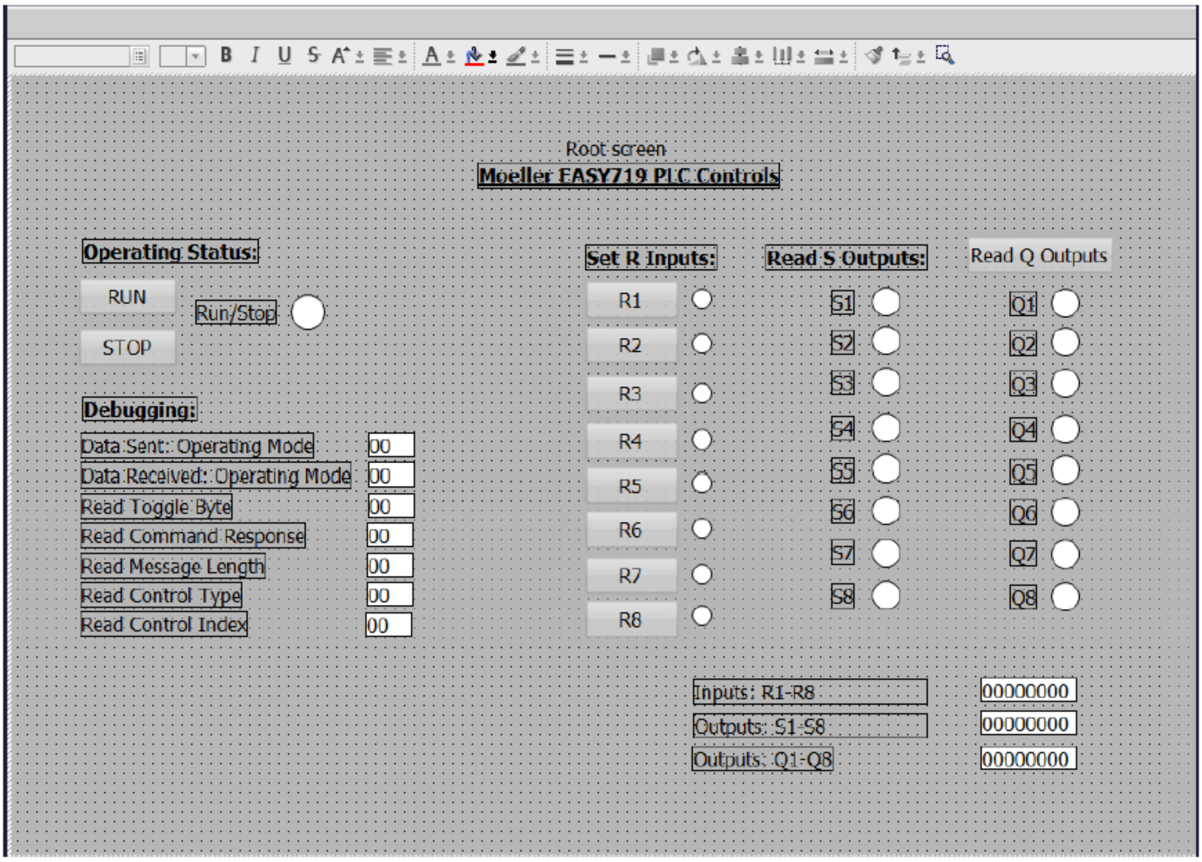


Figure 43 WinCC PC HMI for monitoring/control of the Moeller EASY719 PLC example [29]

Once the EASY719 screen has been developed, students will be asked to design another one but instead for the SEW VSD connected on the network. This screen will need to:

- display the speed (in RPM) of the motor connected to the VSD
- display the output current of the VSD
- have a slider control for the speed set-point of the motor.

Once again, an example image of a screen will be provided, shown below in Figure 44, to assist students in visualising what their developed screen should resemble.

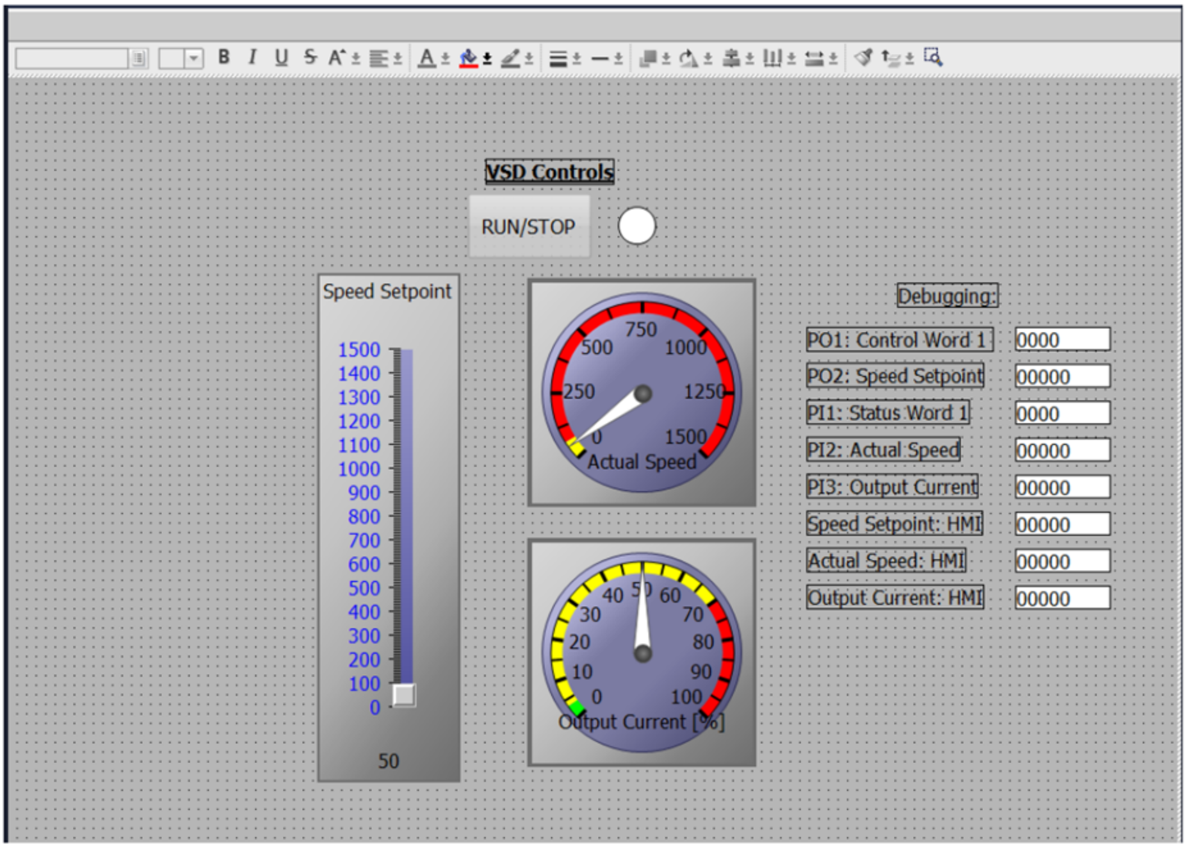


Figure 44 WinCC PC HMI for VSD monitoring/control example [29]

5.2.2 Two Panels – Process Simulation

In this learning module, students will expand their SCADA network to include both sides of their panel as shown below in Figure 45.

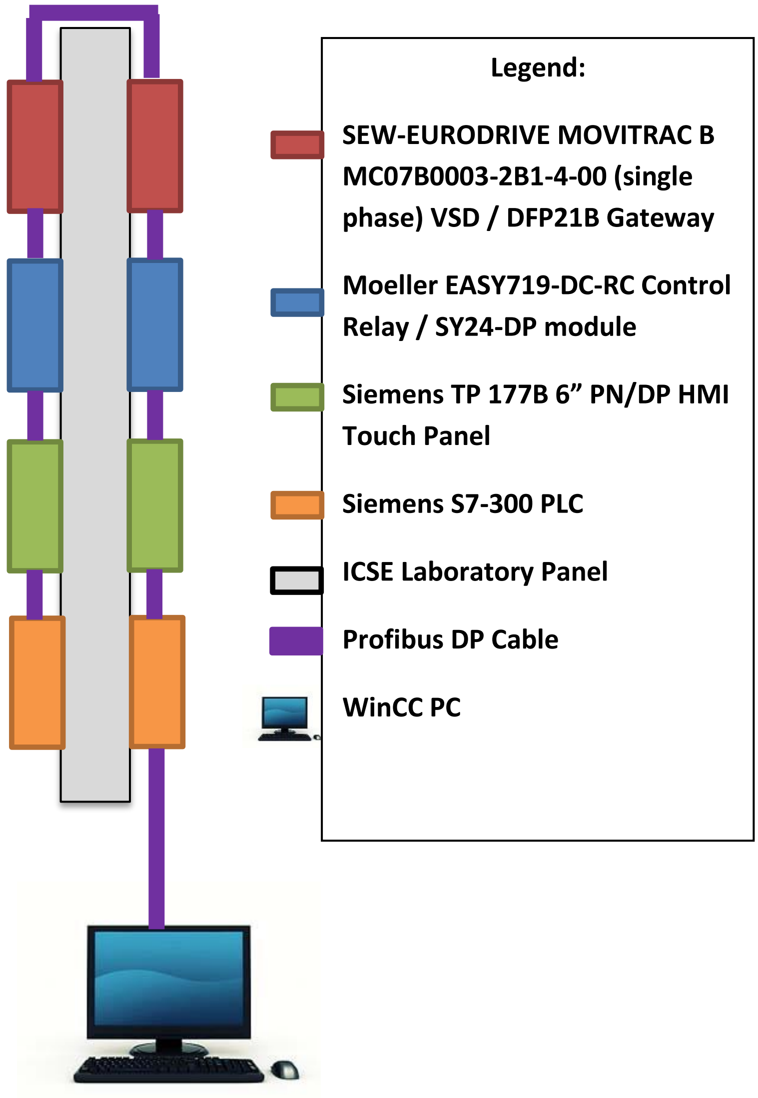


Figure 45 Two panel WinCC Profibus network layout, based on [53].

After the Profibus network has been setup, students will use one S7-300 PLC (the slave) to simulate a first order process. The process will be a simulation of a tank being filled, via a single inlet, with liquid draining out of a single outlet.

The slave PLC will need to communicate with the master PLC, sending the following information:

a. The tank's liquid inflow, $\mathbf{F_i}$ (controlled by a pump)

    i. This could be modelled using a potentiometer (acting as a pump control)

b. The liquid level of the tank, **h**

c. The liquid outflow of the tank, **ch**, where c is the valve resistance

    i. Since ch is the outflow, we are assuming outflow is directly proportional to the liquid level

    ii. If using units m^3s^{-1} for liquid flow, assume c = 0.001

d. Use the equation below to model:

$$A_C \frac{dh}{dt} = F_i - ch$$

Where A_C is the cross-sectional area of the tank in m^3 and dh/dt is the change in tank height with respect to time in m/s . This equation is based on the linear tank model from [54].

Students will develop a PC HMI screen displaying this data similar to that shown below in Figure 46.

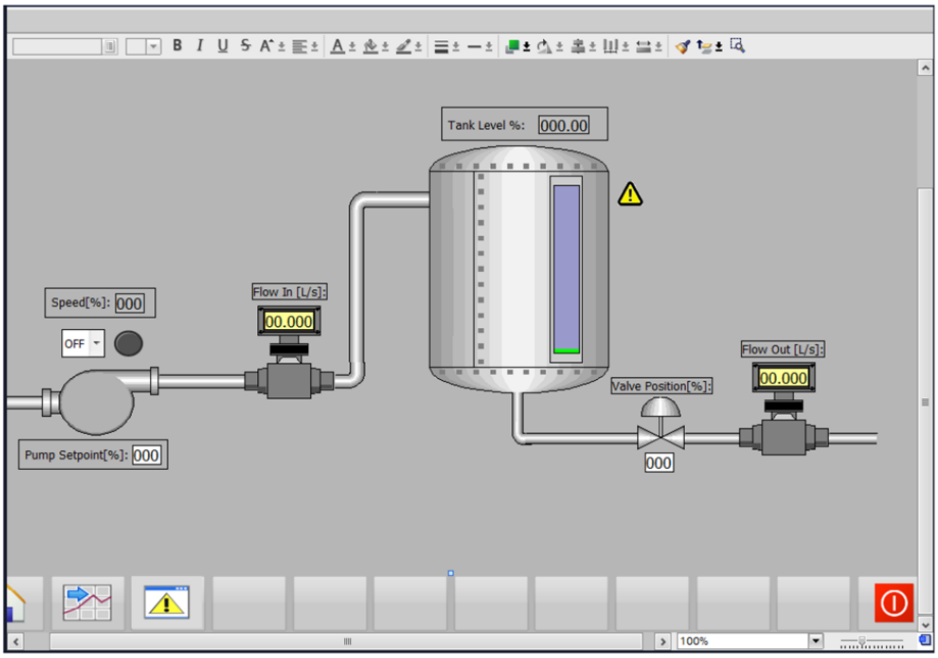


Figure 46 WinCC RT Professional tank process HMI screen [29]

To replicate an actual plant, the SEW VSD will be used to simulate the pump speed of the pump sending liquid into the tank.

The alarm functionality of WinCC will be explored by asking students to set an alarm that triggers when the tank level exceeds 80%, similar to one that would likely exist in a real process plant (shown below in Figure 46).

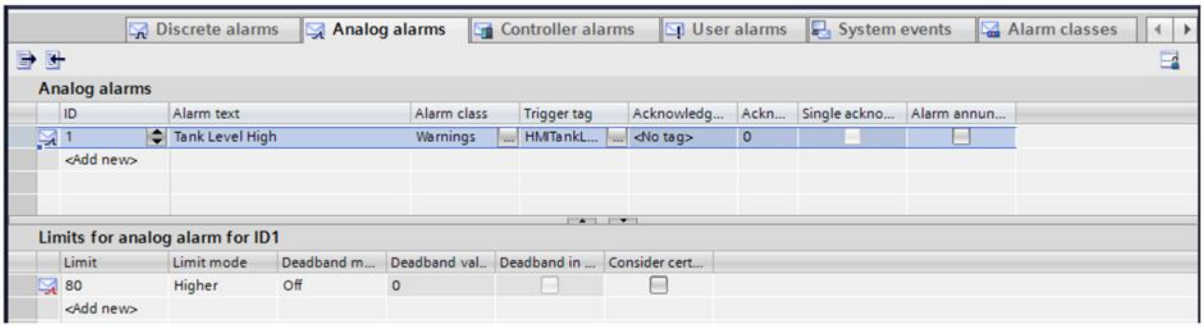


Figure 47 WinCC RT Professional alarm triggered when a simulated tank exceeds 80% capacity [29]

WinCC's logging functionality will also be used by having students log the tank level and speed of the VSD every two seconds which will then be stored in a database for historic viewing of values and trending (shown below in Figure 48).

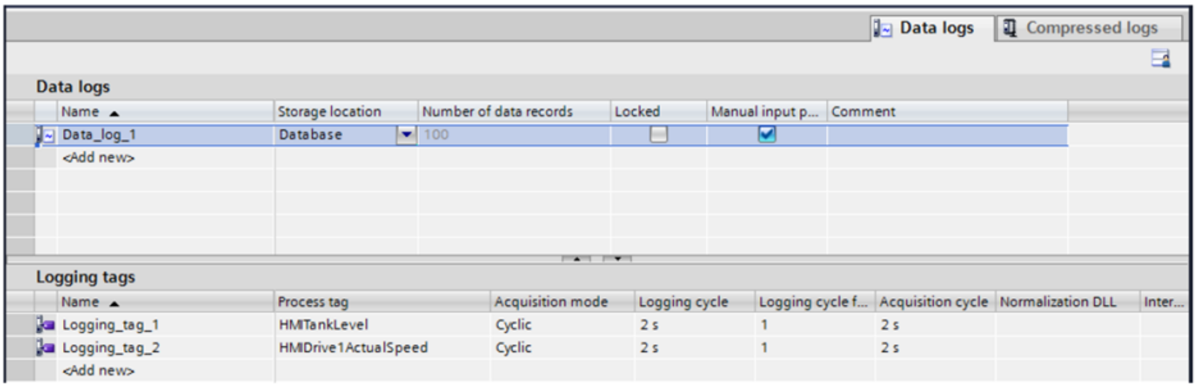


Figure 48 WinCC RT Professional data log used to monitor the simulated process [29]

These exercises were developed to replicate what James Wiggins [29] did in his thesis project.

5.2.3 Four Panels

This learning module sees students expand their two panel SCADA network developed in the previous module to one with four panels shown in Figure 49. This will essentially split the class into half with half the students working on panels one to four and the other half on panels five to eight.

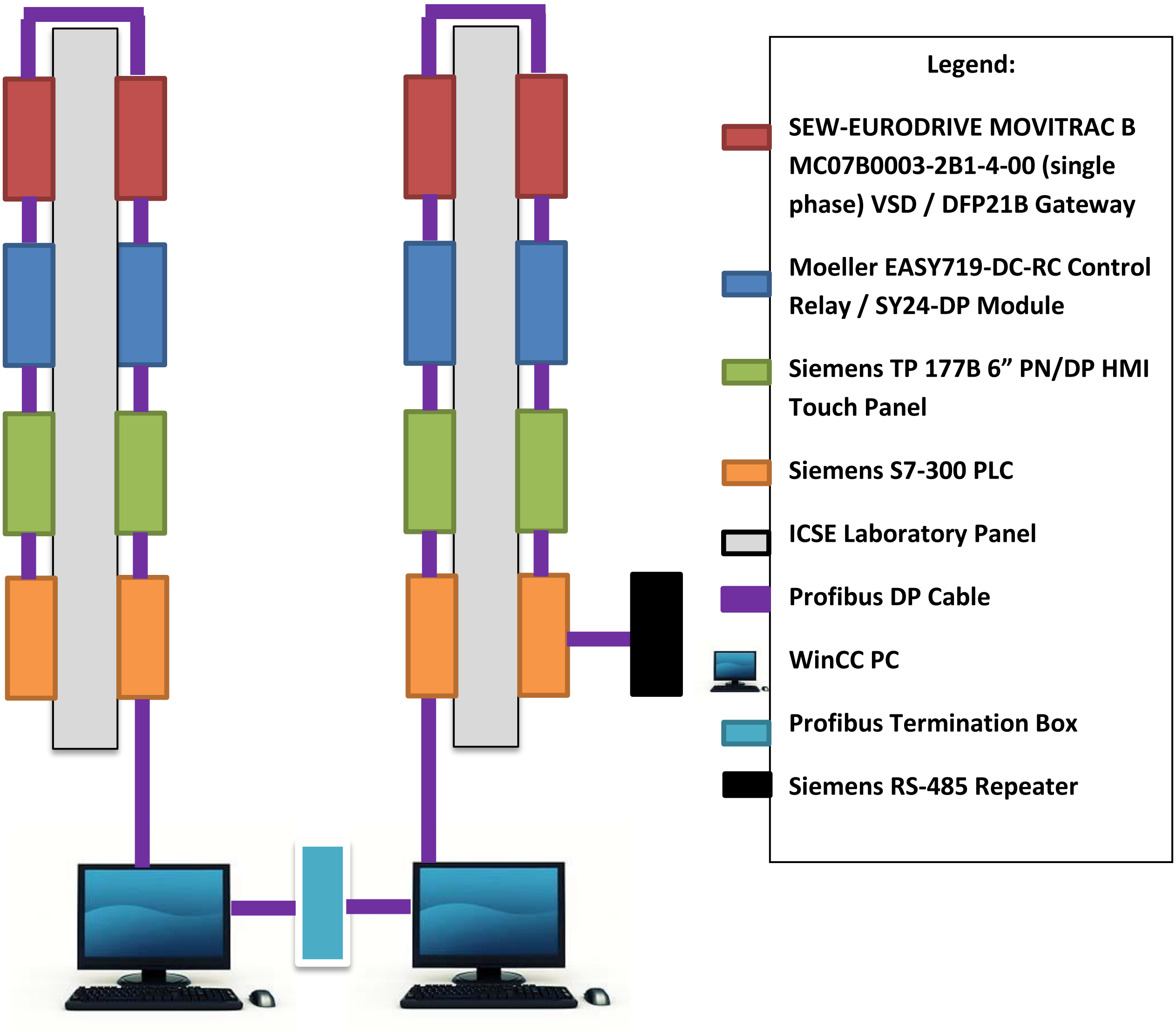


Figure 49 Four panel WinCC Profibus four panel layout, based on [53]

It is important that students ensure the RS-485 repeater is terminated to isolate their network from the other half of the class.

The Profibus Termination Box also needs to be configured correctly to allow the two computers to communicate. For this, students are referred to a section of Jonty Marten's thesis describing how to use the Network Diagnostics Tool in the SIMATIC Manager to test the termination box.

The termination box allows for isolation between sets of panels. If for some reason the in-house developed termination box proves ineffective and communication between PCs is not achieved, an RS-485 repeater may be used instead.

Since two CP5611 card equipped PCs are used in this module, one will be setup as a WinCC server, the other as a client WinCC HMI.

Since no specific SCADA application networks of this size had been developed by previous students, current students are asked to simulate a plant/process of their choice, utilising the four panel network and subsequent devices.

5.2.4 Eight Panels

The final WinCC learning module involves connecting all eight panels in the ICSE Lab Room together and controlling them via one WinCC server configured PC and three subsequent WinCC client HMIs.

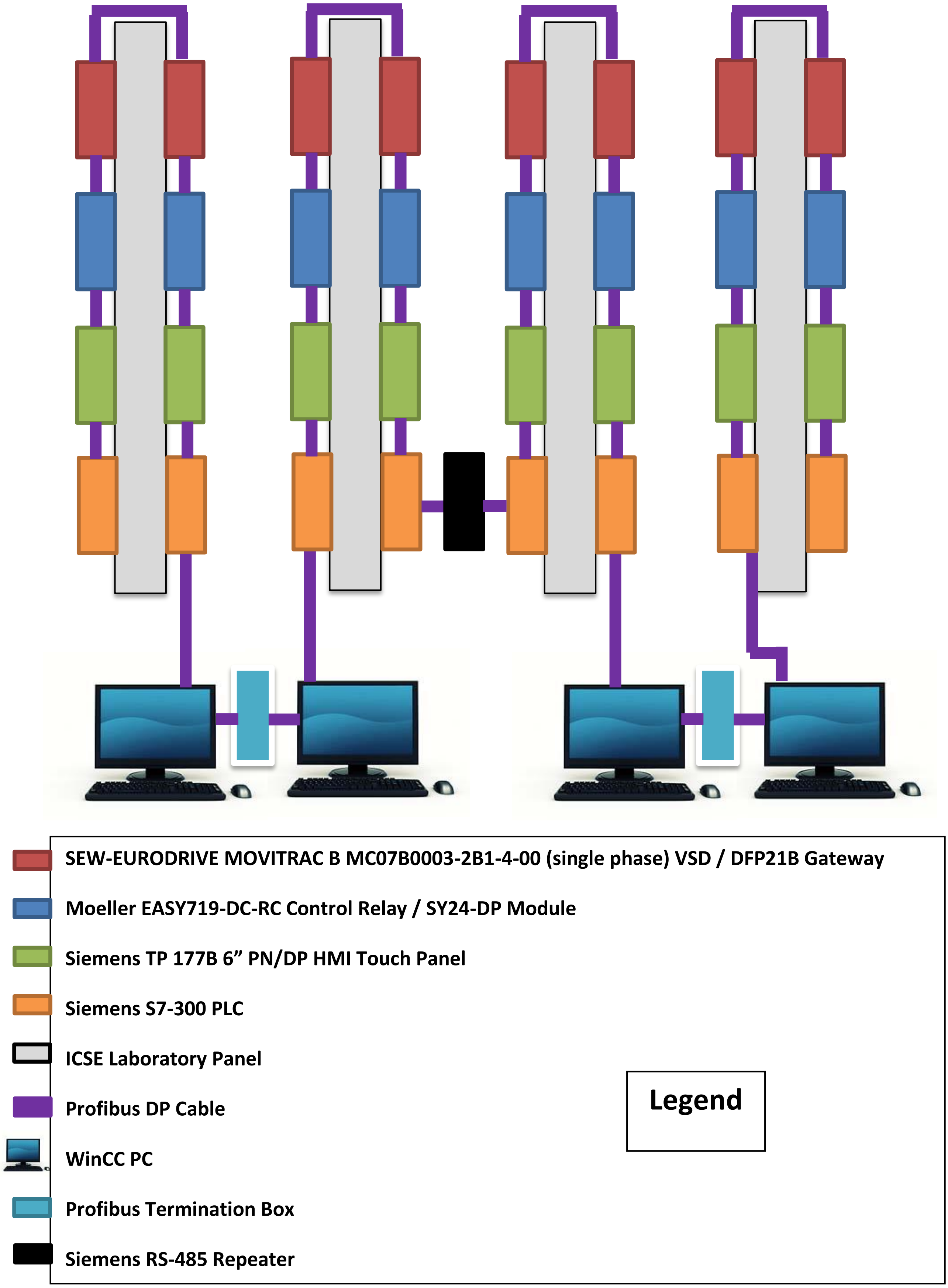


Figure 50 Eight panel WinCC Profibus layout, based on [53]

This learning module will see the entire class working together as a single group, giving the students a chance to experience working in a large group (20+) which is likely what they will encounter once they start working as engineers.

Similar to the four panel module, no actual documented eight-panel examples for students have been produced, so it is left up to the students to decide how they implement their eight panel configuration. They are asked to simulate some sort of plant or process utilising as much of the panel hardware as possible.

5.3 Profinet

5.3.1 Introduction

Now that students have become proficient in developing and using Profibus industrial networks a second industrial networking standard is introduced, namely Profinet [12]. Similar to the Profibus learning modules, students are first introduced to the theory related to Profinet through both written and multimedia materials (consisting of a video [27]).

They then undertake a series of practical laboratory based learning modules where they setup Profinet networks and configure hardware to operate and communicate over these networks. Towards the end of these learning modules, students will integrate a Profinet network into a Profibus network, achieving a hybrid network representative of real industrial plants.

When the Profinet learning modules begin is up to the unit coordinator to decide, however it is suggested that the Profinet learning modules begin after the two panel WinCC module. This way students are very familiar with Profibus networks and monitoring/controlling them via a SCADA system. Once the Profinet learning modules have been completed, the final two modules of the unit are the four and eight panel WinCC modules where students can use their knowledge to develop large hybrid networks made up of both Profibus and Profinet subnets.

Since Profinet has never been taught at Murdoch University, students have never been exposed to most of the hardware introduced in these learning modules. It is hoped, however, that the skills students developed in setting up/configuring new hardware in the

Profibus learning modules will carry over to the Profinet modules, allowing students to use this confidently use this new hardware.

5.3.2 S7-1200 PLC

The first practical Profinet learning module involves students establishing their first Profinet network consisting of a PC and S7-1200 series model CPU1214C DC/DC/DC (S7-1200) [55] controller manufactured by Siemens shown below in Figure 51. The network structure of this learning module is shown in

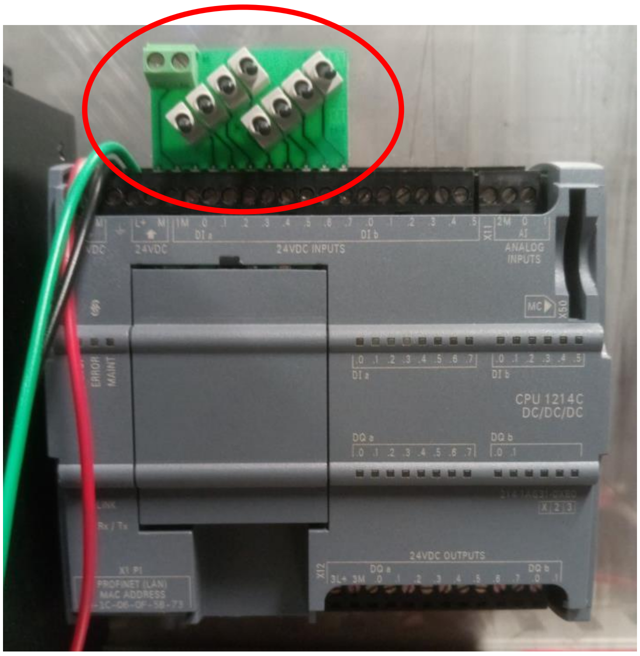


Figure 51 SIMATIC S7-1200 Series CPU 1214C DC/DC/DC model PLC with Simulator Switch Module mounted (circled)

The S7-1200, is intended for low to medium complexity device automation tasks including conveyor/belt reeling, level control and food processing systems [56]. Similar to the S7-300 used in the Profibus learning modules, the S7-1200 are configured and programmed using TIA Portal or specifically, SIMATIC STEP 7.

This controller features transistor outputs that apply a small current to a transistor base to 'close' the triggered output [17]. The PLC has 16 inputs (14 digital and 2 analogue) and 10 digital outputs, all of which have individual LED indicators for displaying their states which can be used for testing logic.

In this module, students first install the S7-1200 and connect a Profinet cable between the integrated Profinet port on the PLC and the panel's PC. The PC used needs to be the one located on the windows (north) side (garden window-facing) of the classroom as these computers have an Intel Pro / 1000 GT Desktop Adapter [57], pictured below in Figure 52 which is required for Profinet RJ45 connectors to be plugged into a PC [22]. This adapter acts as the Profinet interface for device/network configuration, programming and communications. There are eight of these PCs with one assigned to each panel.

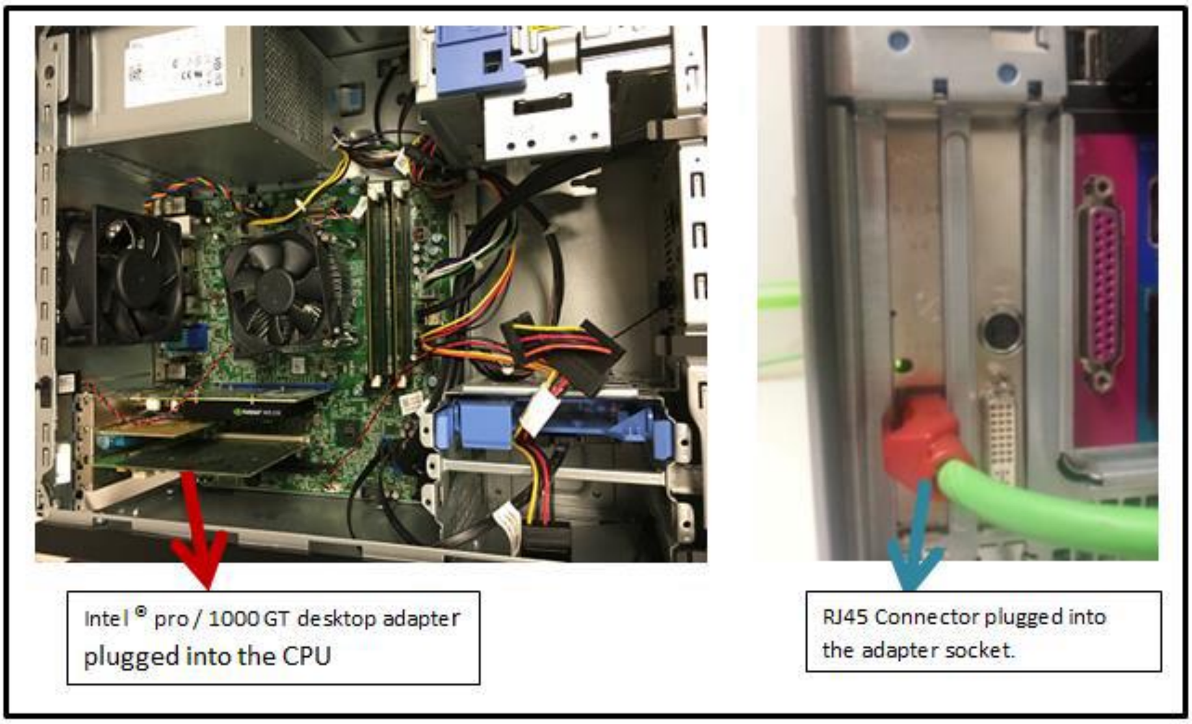


Figure 52 Computer configured with an Intel Pro / 1000 GT Desktop Adapter [22]

Once the hardware is setup, students configure the Profinet network and S7-1200 in TIA Portal. A simple PLC program is then developed to communicate with the PC which can then be tested using a Simulator Switch Module pictured in Figure 51.

The Simulator Switch Module is used to test the logic of developed PLC programs by providing powered on/off switches, which when mounted to a S7-1200, control the PLC inputs [17]. The corresponding output states can then be monitored either via watch tables in TIA Portal or the physical LEDs on the S7-1200. The Simulator Switch Module saves students time in testing and troubleshooting programs because in previous units, students would have to wire individual switches to PLC inputs for triggering. Since students have become proficient at this, this process is removed and allows students to spend more time on learning about their developed networks and subsequent hardware.

This laboratory refers students to configuration manuals produced by both Othman Bensaod [58] and Lewis Glenister [17].

5.3.3 KTP600 Basic Color PM Touch Panel (HMI)

This learning module involves adding a KTP600 Basic Color PN Touch Panel [59] (HMI), shown below in Figure 53, to the controller/PC Profinet network established in the previous learning module. The HMI is similar to the one used in the Profibus learning modules, however this one is designed to operate on Profient networks. It consists of a 5.7 inch touch panel screen and six configurable tactile keys located on the front of the unit. WinCC Basic is used to configure the screens of the HMI. The HMI's specifications are listed below in Table 5.

Figure 53 KTP600 Basic Color PM Touch Panel HMI

Table 5 KTP50 Basic Color PN Touch Panel HMI Specifications, data from [58]

Feature	SIMATIC HMI KTP600 Basic Color
Display	5.7 inch TFT Display, 256 colors
Resolution	320 x 240 pixels
Control elements	Touch screen resistive analog 6 freely configurable tactile keys
User memory	512 KB
Interfaces	1 x RS 485 / RS 422 with Profibus DP-Variant 1 x RJ 45 Ethernet with PRROFINET-Variant
Degree of protection	IP 65 (front if mounted) IP 20 rear
Installation cutout	196 x 140 mm (W x H)
Front panel	214 x 158 mm (W x H)
Device depth	44 mm
Configuration software	WinCC Basic (TIA Portal) / WinCC flexible

Unlike the Profibus learning modules where a 'bus' network topology was used, Profinet, consisting of an industrial Ethernet network physical layer, is a 'switched' network. Since this is the case a CSM 1277 Profinet switch [60] must be setup to allow the HMI to be added to the PLC/PC network from the previous module. Students set up this switch and connect the HMI to the network as shown below in Figure 54.

Figure 54 Profinet HMI learning module network structure, based on [61]

After the HMI is configured in TIA, students create a simple On/Off screen which monitors an input of the PLC and displays its status by using PLC tags.

They then develop a more advanced screen with animations representing a bottle moving along a conveyor belt which varies depending on the input states of the PLC.

Finally, students implement PID control on the simulated conveyor belt. Students have used PID control in previous units and therefore understand this concept.

This laboratory uses Othman Bensaoud's Laboratory Guide [61].

5.3.4 ET200S Distributed I/O

In this learning module, students add an ET 200S Distributed I/O (ET200S) [62], shown in Figure 55, to the PC/PLC/HMI Profinet network established in the previous learning module. All eight panels in the ICSE Lab Room will be equipped with a single ET200S unit

Distributed I/O devices provide slots that I/O modules can be plugged into as needed. The distributed I/O is connected to a central control location – this prevents the need to individually wire all I/O devices to the central control area. Distributed I/O devices are used extensively in large and complex systems. Since they do not usually process logic, they are usually monitored and controlled by a controller such as a PLC [63].

The ET200S housed the following modules:

- IM151-3PN HF PROFINET Interface Module [64]
    - Facilitates the data transfer between input/ output ET 200S modules and the connected PLC.
- 2DI DC24V HF Digital Input Module [65] (note that this reference is for the model with four DIs – the two DI model could not be located)
    - Consists of two 24V digital inputs
- 2DO DC24V/0.5 A HF Digital Output Module [66] (note that this reference is for the model with four DOs – the two DO model could not be located)
    - Consists of two 24V 0.5 A digital outputs
- PM-E DC24-48V Power Module [67]
    - Two Power Modules are used for each ET200S – one for the Digital Input Module, the other for the Digital Output Module. The power modules provide power for the connected modules.

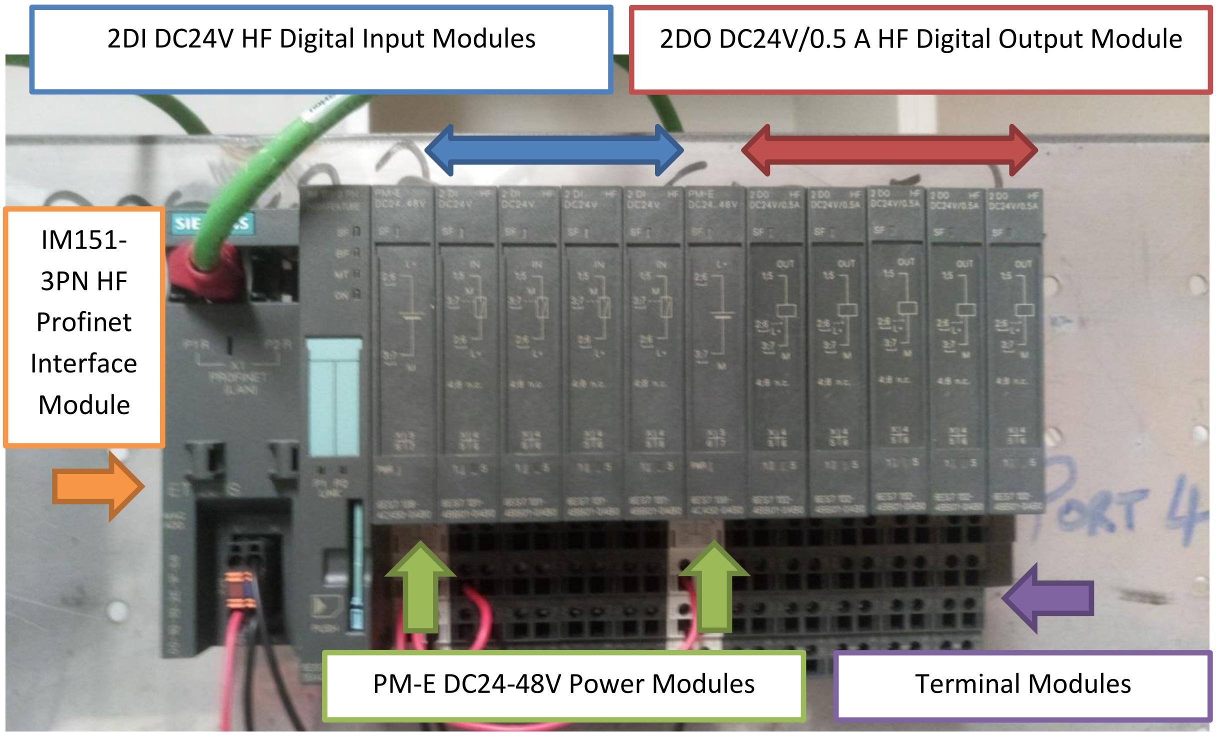


Figure 55 ET200S Distributed I/O device with attached modules, based on [17]

Students connect the ET200S to the CSM1277 switch to form a ‘star’ topology network as shown in.

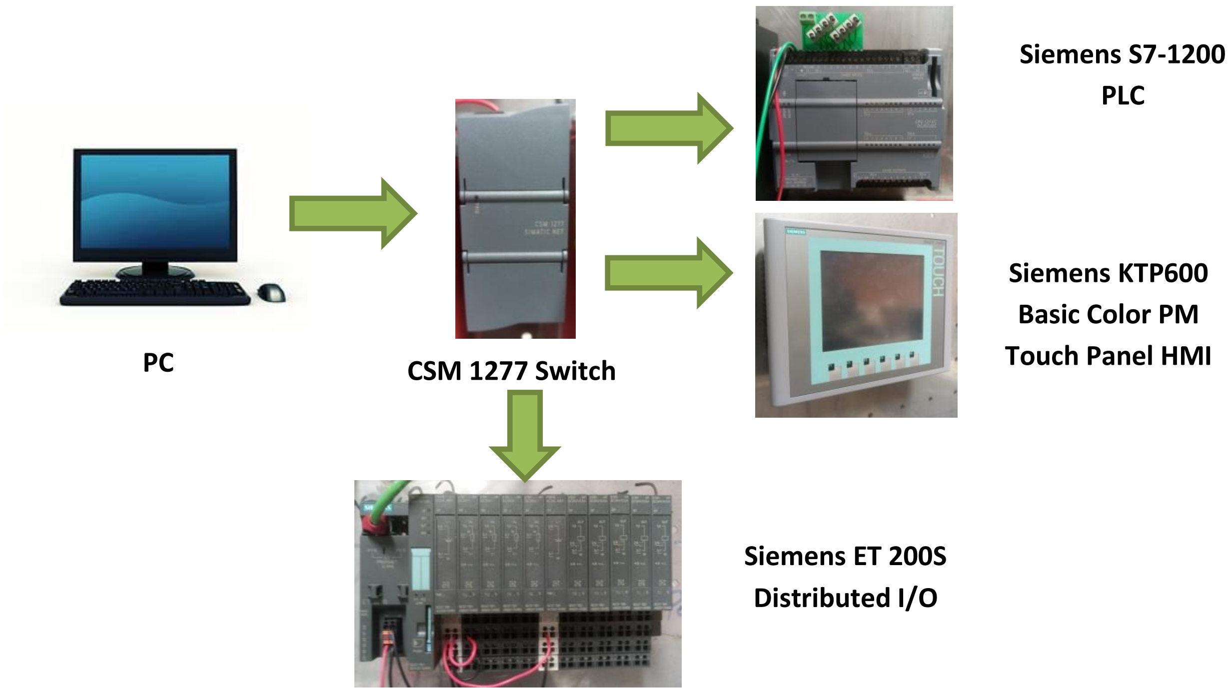


Figure 56 Profinet ETS200 Learning Module network structure, based on [68]

Once configured, switches are attached to the ET200S. This setup represents a situation where the sensors that the S7-1200 needs to monitor are not within close proximity. Rather than having long runs of wires going between the two, an ET200S is installed close to the sensors. Following this, a simple data exchange program is developed to send/receive data between the S7-1200 and ETS200.

This learning module is based off Othman Bensaoud's Lab Guide [68].

5.3.5 S7 OPC

In this module, students will setup an OPC connection for data exchange between a PC and S7-1200 PLC.

OPC is a standard software interface which facilitates the communication between Windows programs and industrial hardware devices [69]. It is based off Microsoft's DCOM technology that allows DCOM objects on different processors, WANs or LANs to communicate through shared memory management when in different physical locations. It was designed for interoperability between different devices and their subsequent diverse communication protocols [22].

A basic structure of an OPC setup is shown below in Figure 57.

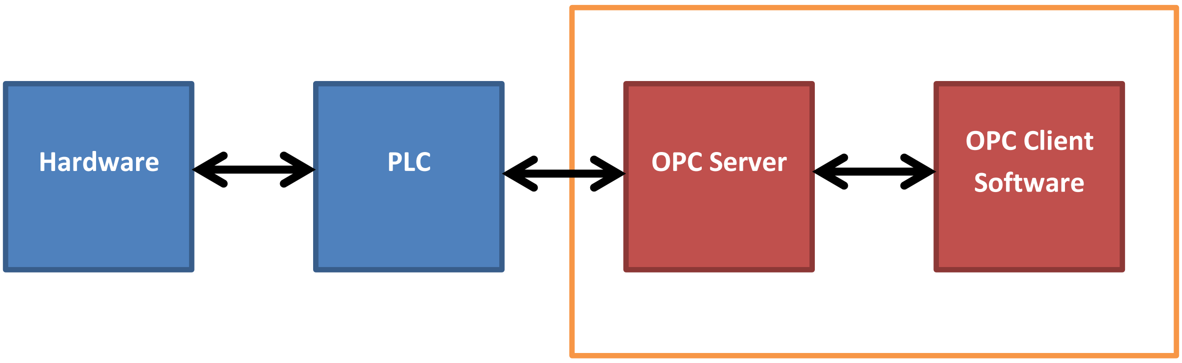


Figure 57 OPC layout, based on [69]

OPC is setup with server/client pairs. The hardware communication of industrial devices like PLCs are converted into the OPC protocol by the OPC server. The OPC client software can be any program that needs a connection to the hardware; a typical program is an HMI. The client uses the server to retrieve data from and send commands to the field hardware.

The key feature of OPC is that it is an open standard, allowing for any OPC client, including multiple ones simultaneously, to communicate to field devices via a single OPC server. Any software with OPC client capabilities can communicate with OPC-enabled hardware. This results in lower costs for manufacturers and greater options for users [69].

This learning module is very important because it builds upon students' knowledge of OPC from previous units in a practical setting. With an understanding of how to setup OPC communications, students can use these skills in almost all industrial network applications, albeit with different software.

5.3.6 MOXA MGate 5102-PBM-PN Gateway

The Moxa MGate 5102-PBM-PN Gateway [70] (Moxa Gateway), pictured in Figure 58, acts as all gateways do, to translate between two different network protocols. This particular gateway translates between Profibus and Profinet protocols. The gateway uses Mgate Software Manager's [70] Autoscan function to scan for any connected Profibus slave devices and connected I/O modules by acting as a master. These are therefore detected automatically in a very fast and intuitive manner. The Profinet controller can therefore send/retrieve data to/from Profibus devices. This unit allows for networks to consist of a Profibus section and Profinet section.

Figure 58 Moxa MGate 5102-PBM-PN Gateway

This learning module involves integrating a Profibus network consisting of a S7-300 slave PLC, a Profinet network consisting of a single (or multiple) S7-1200 controller/s, ET200S and KTP600 HMI (the Profinet network developped in the previous module), shown below in Figure 59. Students follow the steps Lewis Glenister documented in his thesis report [17].

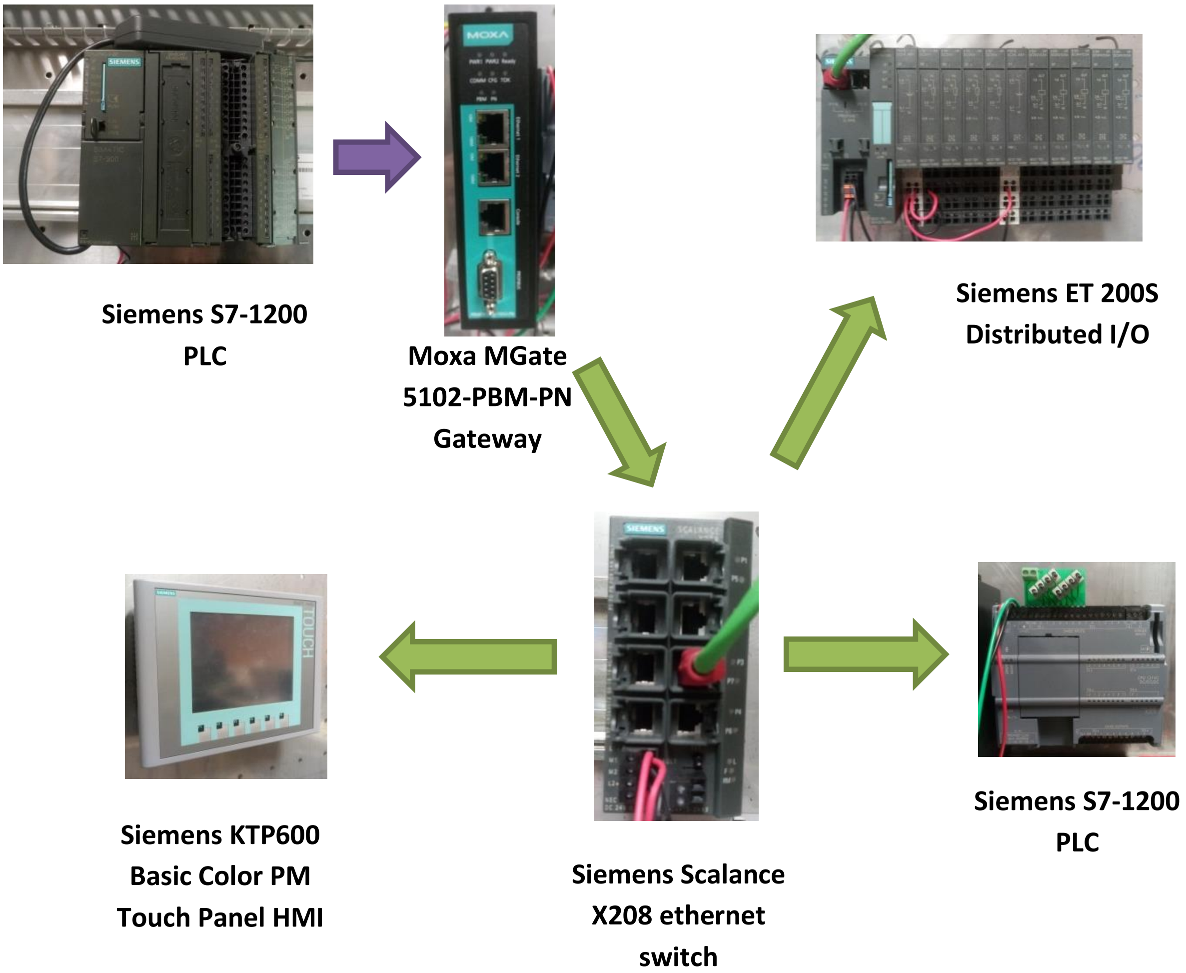


Figure 59 MOXA MGate 5102-PBM-PN Gateway learning module network structure, based on [17].

Depending on the number of devices connected, the CSM 1277 (4 ports) [60] may need to be replaced with a Siemens Scalance X208 ethernet switch (8 ports) [71], pictured in Figure 59.

6.0 Project Summary

6.1 Project Outcomes

The two primary goals of this project were achieved:

1. Existing project materials were researched, assembled, reviewed and simplified
2. Subsequent learning modules were developed encapsulating these materials.

The status of the learning modules are listed below in Table 6.

Time did not permit for the secondary goal of commissioning, configuring and testing the new hardware/network for the ENG448 unit and subsequent learning modules to be achieved. This, as well as other future works items, are discussed in the next section.

Table 6 Learning Module Status'

Technology	Learning Module	Status
Profibus	Introduction	Complete
	Siemens S7-300 PLC Master	Complete
	Siemens HMI Touch Panel	Complete
	Moeller easy719-DC-RC Control Relay	Complete
	RS-485 Repeater	Complete
	SEW Eurodrive MOVITRAC B VSD	Complete
	Danfoss VSD	Complete
	Siemens S7-300 PLC (Slave)	Complete
WinCC SCADA	Introduction	Complete
	One Panel – Moeller + VSD HMIs	Complete
	Two Panels – Process Simulation	Complete
	Four Panels	Incomplete –requires practical examples to be developed/demonstrated
	Eight Panels	Incomplete –requires practical examples to be developed/demonstrated
Profinet	Introduction	Complete
	S7-1200 PLC	Complete
	KTP600 Basic Color PM Touch Panel (HMI)	Complete
	ET200S Distributed I/O	Complete*
	S7 OPC	Complete*
	MOXA MGate 5102-PBM-PN Gateway	Complete*
	Scope for additional Profinet modules to be developed and existing ones marked with * to be expanded	

As discussed in the Introduction, The new or novel aspect of this project was the design of learning modules utilising the existing student-developed engineering learning materials. While unfortunately time did not permit for testing of the developed learning modules, a thorough technical understanding of Profibus, Profinet and WinCC SCADA was established and allowed for the carefully thought out design of university learning materials which utilised and built upon the work of previous students' projects. The author is excited at the prospect of the implementation of these materials in ENG448 and hopes they will continue to grow and expand to meet the requirements of the unit.

6.2 Future Works

6.2.1 Purchase Profibus DP/DP coupler

It was suggested by Bilal Ahmad Khan, the previous student who worked on this project, to purchase a device called a Profibus DP/DP coupler [72] [73]. This device joins or 'couples' two different Profibus networks together, allowing for two master devices on a Profibus network instead of one.

While this was a good idea, it was decided that this would not be procured during this phase of the project for the following reasons:

- Lengthy delivery times would mean the device would not likely be acquired until half way through the semester which would limit the amount of time which could be spent learning how to use the device.
- As has been evident in the previous phases of this project, learning how to use a new piece of hardware can take a very long time, particularly when it comes to implementing it into a physical network. While there is scope for additional technologies/hardware to be included in ENG448, it was decided that taking the time to learn how to use a new piece of hardware could jeopardise the primary objectives of this phase of the project, namely the development of learning modules. Since these learning modules needed to be ready for Semester One 2017 it was decided that it was not in the scope for this phase of the project to procure and learn new technologies.
- More than 85% of Profibus systems are single master networks [6]. Therefore the content already covered represents are large proportion of how Profibus networks

are implemented in the real world. While it would be beneficial to learn about multi-master Profibus networks, these are only applied in limited applications in the real world, which means the relevance of this approach is much less than single master networks.

If it is decided to purchase a DP/DP coupler, work will need to be conducted in implementing a 'token passing' mechanism for a multi-master Profibus network. Since no work has been done on multi-master networks, no work has previously been undertaken to achieve this.

Token passing [74] allows multiple masters to communicate without clashes by having one master communicate at a time. This is similar to the concept of a 'talking stick' when a group of people are talking but only one person is allowed to talk at a time. The token or 'talking stick' is passed around to each master, one at a time, until all masters have communicated to their subsequent slave devices. The process then repeats indefinitely.

While it was decided that a Profibus DP/DP coupler would not be purchased during this phase, research was conducted into suitable products. One candidate is the Siemens DP/DP Coupler article number 6ES7158-0AD01-0XA0 [72] [73] (section 3 page 255). Siemens was considered a desired manufacturer because the ICSE Lab already has many Siemens products and Siemens produce many Profibus related products.

6.2.2 Housing for Danfoss VSD's Three Phase Power Terminals

One of the new technologies introduced in ENG448 will be the Danfoss VSD. Since this VSD (and its subsequent attached motor) are powered by three phase power, students are not permitted to access the power components which carry dangerous voltage levels.

Although there are no exposed wires, with insulated cabling being used, a Perspex housing, similar to that shown in Figure 60, should be installed around the terminals of the VSD, shown in Figure 61, to enhance the safety of this device by making the terminals inaccessible to future students.

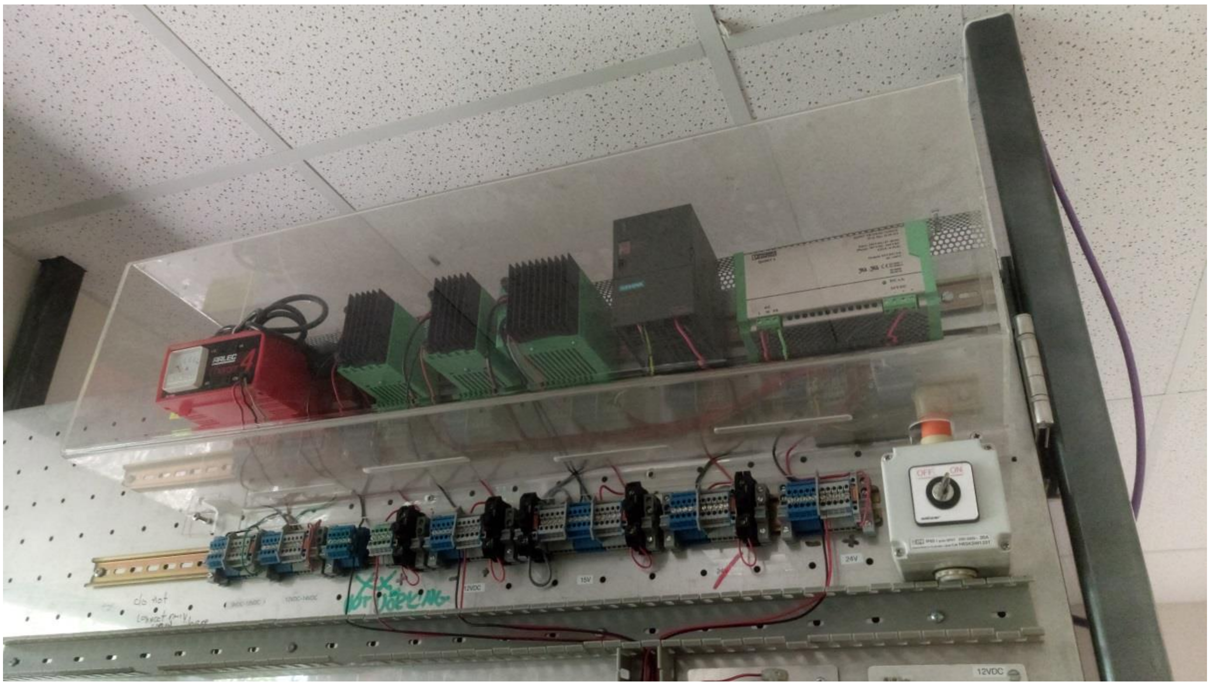


Figure 60 Existing power supply Perspex enclosure in ICSE Laboratory

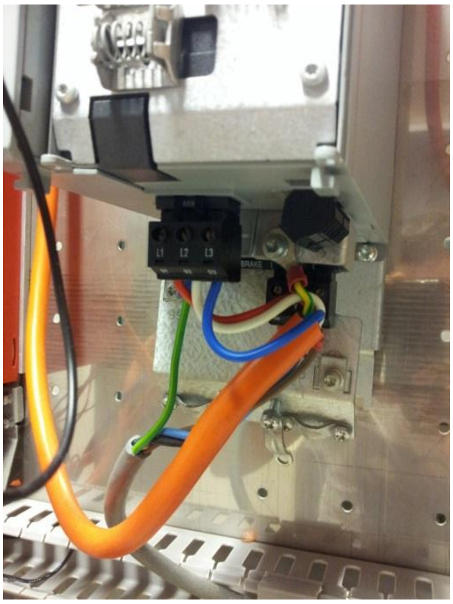


Figure 61 Danfoss VSD terminals

6.2.3 Commission, Configure and Test Network and Hardware in ICSE Lab Room

The Profibus/Profinet networks and subsequent hardware will need to be set up and mounted to the panels before the beginning of semester one 2017. As is understood, the computers are equipped with their necessary interface cards. Specifically, the following items need to be addressed:

1. Set up the Profibus network
    a. Some Profibus network elements exist in the ICSE room but it is not complete. The design proposed by Jonty Martens [53] (see Figure 50) requires a termination box to be fitted for each pair of Profibus equipped PCs on the entry/exit side of the ICSE Lab. There are four of these PCs in total. If these termination boxes are not ideal, RS-485 repeaters may be used in place of them.
    b. The Profibus cable will be run through the ceiling to remove tripping hazards.
    c. This network was proposed in 2013 so there is scope for amendments if this is seen fit.
2. Set up hardware
    a. The Profibus hardware consists of one SEW VSD and motor mounted on each panel (eight in total). The other listed items are already setup.
    b. The Profinet hardware consists of the following items for each panel:
        i. S7-1200PLC + Simulator Switch Module
        ii. KTP600 Basic Color PM Touch Panel
        iii. ETS200S Distributed I/O
        iv. Moxa MGate 5102-PBM-PN gateway
        v. Scalance industrial Ethernet switch

    These devices will interface with their corresponding panel's PC located on the garden-facing window (north) side of the room via the S7-1200. Therefore the S7-1200 for each panel needs to be situated closest to this PC.

3. Test Network / Hardware / Learning Modules
    a. Testing does not need to be extensive as it will be the students' job in ENG448 to setup/configure the hardware.
    b. Since the learning modules were designed to be completed over a 16 week university semester, time did not permit for testing of every learning module. If time permits, this would be a good chance to confirm that the network/hardware function as they should.

6.2.4 Further module development

Some modules did not have as much material developed for them as others. Most notable are the ones below:

- WinCC Four/Eight Panel Modules – While students can use the skills they developed in earlier WinCC modules to setup/configure the panels in these arrangements, no application examples had been developed by previous students and hence students are asked to design their own applications simulating a real plant. While this is fine, it would be good if actual examples of WinCC configurations are provided to help guide students in understanding how best to implement/represent a simulation of a real world larger scale SCADA system. Ideally, students will be provided with a specification of what needs to be achieved for them to then design/implement the necessary components.
- Profinet – Most of the work over the years for this project has been dedicated to Profibus. Profinet modules could be expanded and elaborated upon. Once again this is not a huge problem because students will be able to use the skills they developed in the more detailed Profibus learning modules and apply them in a Profinet context.

6.2.5 Forum

An idea proposed for ENG448 is the implementation of a forum for students to assist each other even when other students aren't physically present in the laboratories.

A lot of laboratory work in previous ICSE units involves troubleshooting and diagnostics. Sometimes these problems are actually quite simple but without the guidance of other students can be difficult to solve.

It is hoped that this could provide a platform for students to share common problems they experience and how to fix them.

This has been proposed and is being looked into – the primary element involved is that such a forum would have to be moderated.

To take this idea further, the forum could be linked to a Wiki containing the modules, allowing future students to correct/improve the learning modules.

7.0 References

[1] Siemens, “SCADA System SIMATIC WinCC,” 2016. [Online]. Available: http://w3.siemens.com/mcms/human-machine-interface/en/visualization-software/scada/pages/default.aspx. [Accessed 11 9 2016].

[2] RTA, “Comprehensive Protocol Overview,” 2016. [Online]. Available: http://www.rtaautomation.com/technologies/profibus/. [Accessed 7 9 2016].

[3] Fieldbus Foundation, “The Power of Digital for your Process Devices,” [Online]. Available: http://www.fieldbus.org/images/stories/technology/aboutthetechology/overview/fieldbus_brochure.pdf. [Accessed 4 8 2016].

[4] Minarik Training, “Training in 60 Seconds - Fieldbus (Part 1/5),” 7 7 2009. [Online]. Available: https://www.youtube.com/watch?v=EMt0aOZyEls. [Accessed 1 10 2016].

[5] ATS, “PROFIBUS technology,” [Online]. Available: http://www.ats-global.com/profibus-technology_230_nlnl. [Accessed 11 9 2016].

[6] ISA, “1-Basics odf Profibus Operation - ISA,” [Online]. Available: https://www.isa.org/pdfs/basics-of-profibus-operation-chapter1/. [Accessed 5 9 2016].

[7] B. Walker, “Development of a Profibus Network and WinCC SCADA environment for Educational Purposes,” Murdoch Univ, Perth, 2011.

[8] N. Instruments, “RS-232, RS-44, RS-485 Serial Communication General Concepts,” National Instruments, 29 Jun 2016. [Online]. Available: http://www.ni.com/white-paper/11390/en/. [Accessed 7 Sep 2016].

[9] M. B. M. B. G. Vijayaraghavan, “Electrical noise and mitigation – Part 2: Groundoops, noise transmission and shiedling,” in *Grounding, Bonding, Shielding and Surge Protection*, Butterworth Heinmann, 2004, pp. Sections 8.8 - 8.9.

[10] D. X. Ji, “PROFIBUS Project,” 5 October 2010. [Online]. Available: http://www.profibus.com/uploads/media/pxddamkey%5B9233%5D_FA_2010_Oct_2_Successful_Profibus_Project_XiuJi.pdf. [Accessed 28 10 2016].

[11] M. Felser, “The master - slave principle,” 2013. [Online]. Available: http://profibus.felser.ch/en/index.html?prinzip_des_master-slave.htm. [Accessed 10 9 2016].

[12] PI, “Profinet, industrial Ethernet for advanced manufacturing,” 2016. [Online]. Available: http://us.profinet.com/technology/profinet/. [Accessed 15 10 2016].

[13] D. Lane, “Introduction to PROFINET,” 28 August 2013. [Online]. Available: http://www.slideshare.net/ProfibusUK/introduction-to-profinet-derek-lane. [Accessed 23 9

2016].

[14] Siemens, “SIMATIC PROFINET System Description System Manual,” 6 2008. [Online]. Available: http://www.siemens.fi/pool/products/industry/iadt_is/tuotteet/automaatiotekniikka/teollinen_tiedonsiirto/profinet/man_pnsystem_description.pdf. [Accessed 17 10 2016].

[15] IEC, “What is Simplex, Half-Duplex & Full-Duplex,” 2016. [Online]. Available: http://www.iec-usa.com/Browse05/DTHFDUP.html. [Accessed 4 10 2016].

[16] A. Dopplinger, “Why so many Industrial Network Protocols,” 21 6 2007. [Online]. Available: http://www.embedded.com/print/4013718 (accessed January 14, 2016). [Accessed 10 10 2016].

[17] L. Glenister, “PROFINET Training Package,” Murodch Univ, Perth, 2016.

[18] ControlControlDesign, “Back to Basics: SCADA,” 18 August 2009. [Online]. Available: https://www.youtube.com/watch?NR=1&v=bfxr5DikdP0. [Accessed 21 9 2016].

[19] R. Singh, “E- Learning SCADA Lesson 1 - What is SCADA,” 31 March 2015. [Online]. Available: https://www.youtube.com/watch?v=5ZiIA-kMV8M. [Accessed 12 8 2016].

[20] National Communications System, “Supervisory Control and Data Acquisition (SCADA) Systems,” October 2004. [Online]. Available: https://scadahacker.com/library/Documents/ICS_Basics/SCADA%20Basics%20-%20NCS%20TIB%2004-1.pdf. [Accessed 3 10 2016].

[21] H. Xu, “WINCC SCADA SYSTEM VIA PROFIBUS & OPC,” Murdoch Univ, Perth, 2012.

[22] B. A. Khan, “WinCC SCADA and Profibus Network for Murdoch University Engineering Laboratory,” Murodch Univ, Perth, 2016.

[23] Siemens, “SIMATIC STEP 7 Professional,” Siemens, 2016. [Online]. Available: http://w3.siemens.com/mcms/simatic-controller-software/en/step7/step7-professional/pages/default.aspx#Supported_20Operating_20systems. [Accessed 23 Aug 2016].

[24] SEW-EURODRIVE, “SEW-EURODRIVE system buses,” SEW-EURODRIVE, [Online]. Available: https://www.sew-eurodrive.com.au/products/industrial_communication/sew-eurodrive_system_buses/sew-eurodrive_system_buses.html. [Accessed 5 Sep 2016].

[25] RealPars, “What exactly is Profibus-DP in layman's terms,” 28 10 2014. [Online]. Available: https://www.youtube.com/watch?v=zJDsEqCyTqc&feature=youtu.be. [Accessed 1 10 2016].

[26] Learning Engineering, “Profibus | What is Profibus | How does Profibus work | Profibus dp,” 25 7 2016. [Online]. Available: https://www.youtube.com/watch?v=iZxz33VTlws&feature=youtu.be. [Accessed 39 9 2016].

[27] Indu-Sol GmbH, "PROFINET - The Movie | Technology Made Easy," 22 July 2016. [Online]. Available: https://www.youtube.com/watch?v=lLwsUoSgwPA. [Accessed 17 9 2016].

[28] M. Staib, "Provertha Assembly Video Profibus Bus Connector Internal Cable Clamp," 22 1 2013. [Online]. Available: https://www.youtube.com/watch?v=-NrkkhQtV1M. [Accessed 30 9 2016].

[29] J. Wiggins, "Development of a WinCC and ProfiBus System for Teaching Purposes: Progress Report for Bachelor of Engineering Thesis Project," Murdoch Univ, Perth, 2015.

[30] Moeller, "User Manual easy500, easy700 Control Relay," Moeller GmbH, Bonn, 2004.

[31] AMCI, "What is a PLC?," [Online]. Available: https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/. [Accessed 12 9 2016].

[32] Siemens, *SIMATIC S7-300 S7-300 Module Data Manual,* NÜRNBERG, 2013.

[33] J. Wiggins, *Siemens S&-300 PLC & RS-485 Repeater Profibus Configuration Guide,* 2015.

[34] A. Tokmechi, O. Bensaoud and N. B. M. Nain, "ENG454 Phase 2 Profibus DP".

[35] Siemens, "SIMATIC HMI - HMI Device TP 177A, TP 177B, OP 177B (WinCC flexible) Operating Instructions," 8 2008. [Online]. Available: https://cache.industry.siemens.com/dl/files/461/21084461/att_82592/v1/hmi_tp177a_tp177b_op177b_operating_instructions_en_US_en-US.pdf. [Accessed 7 10 2016].

[36] Moeller, *EASY204-DP PROFIBUS-DP Slave Interface,* Eaton Industries GmbH, 53105 Bonn, 2010.

[37] J. Wiggins, *Moeller EASY719-DC-RC Control Relay Profibus Configuration Guide,* 2015.

[38] A. Tokhmechi, O. Bensaoud and N. B. M. Nain, *ENG 454 Phase 2 Profibus DP.*

[39] Siemens, *SIMATIC RS 485 Repeater,* NÜRNBERG, 2011.

[40] ABB, "What is a variable speed drive?," 21 November 2008. [Online]. Available: http://www.abbaustralia.com.au/cawp/db0003db002698/a5bd0fc25708f141c12571f10040fd37.aspx. [Accessed 25 8 2016].

[41] O. Hydro, "Adjustable Speed Drive Reference Guide," 8 1997. [Online]. Available: http://web.stanford.edu/group/narratives/classes/08-09/CEE215/ReferenceLibrary/Variable%20Speed%20Drives%20(VSD)/Adjustable%20Speed%20Drive%20Reference%20Guide.pdf. [Accessed 3 10 2016].

[42] E. Parliament, "DIRECTIVE 2014/35/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL," *Official Journal of the European Union,* 2014.

[43] I. E. Commission, "IEC 61800-3:2004," 2004. [Online]. Available:

https://webstore.iec.ch/publication/5933. [Accessed 3 Sep 2016].

[44] SEW-EURODRIVE, “Helical Gearmotor R Series,” 2014. [Online]. [Accessed 20 8 2016].

[45] J. Wiggins, “SEW Eurodrive MOVITRAC B VSD Profibus Configuration Guide,” 2015.

[46] S. EURODRIVE, “MOVITOOLS MotionStudio,” 2016. [Online]. Available: http://www.seweurodrive.com/produkt/movitools-motionstudio.htm. [Accessed 18 Sep 2016].

[47] SEW-EURODRIVE, “Fieldbus Interface DFP21B,” 2006. [Online]. Available: http://download.sew-eurodrive.com/download/pdf/11479019.pdf. [Accessed 2 Oct 2016].

[48] SEW EURODRIVE, “MOVITRAC B FSC11B Communication Interface FIO11B Analog Module / FIO21B Digital Module Operating Instructions,” 2009. [Online]. Available: http://download.sew-eurodrive.com/download/pdf/16793226.pdf. [Accessed 4 10 2016].

[49] Danfoss, “VLT HVAC Drive Operating Instructions,” [Online]. Available: http://files.danfoss.com/documents/PE/doc_MG11A602.pdf. [Accessed 4 10 2016].

[50] H. Berger, “Automating with SIMATIC S7-1200,” Publicis Publishing, Erlangen, 2013.

[51] Siemens, “Profibus cards,” 1999. [Online]. Available: https://w5.siemens.com/web/sk/sk/produkty_sluzby/technologie-budov/katalogove-listy/Katalogove_listy_80008999/n8554en.pdf. [Accessed 5 10 3].

[52] J. Wiggins, *WinCC Runtime Professional Profibus Configuration Guide,* 2015.

[53] J. Martens, “Siemens Profibus System For Teaching Purposes,” Murdoch Univ, Perth, 2013.

[54] W. H. R. Babatunde A. Ogunnaike, Process Dynamics, Modeling, and Control, New York: Ocford University Press, 1994.

[55] Siemens, “SIMATIC S& S&-1200 Programmable controller System Manual,” 1 2015. [Online]. Available: https://cache.industry.siemens.com/dl/files/221/107623221/att_69705/v1/s71200_system_manual_en-US_en-US.pdf. [Accessed 10 10 2016].

[56] T. Piiparinen, “Development of a PLC-based Control & Monitoring,” Metropolia University of Applied Sciences, Helsinki, 2014.

[57] Intel, “Intel PRO/1000 GT Desktop Adapter Overview,” [Online]. Available: http://www.intel.com/Products/Desktop/Adapters/PRO1000GT/PRO1000GT-overview.htm#content. [Accessed 1 10 2016].

[58] O. Bensaoud, “Laboratory guide 1(PLC connection),” Murdoch Univ, Perth, 2013.

[59] Siemens, “SIMATIC HMI HMI device KTP400 Basic, KTP600 Basic, KTP1000 Basic, TP1500 Basic Operating Instructions,” 8 2008. [Online]. Available: https://www.automatyka.siemens.pl/docs/docs_ia/HMI_KTP400_KTP600_KTP1000_TP1500.pdf. [Accessed 11 10 2016].

[60] Siemens, “SIMATIC NET S7-1200 Compact Switch Moduke CSM 1277,” 8 2010. [Online]. Available: https://www.rapidonline.com/pdf/540317_v1.pdf. [Accessed 2 10 2016].

[61] O. Bensaoud, “Developing a Profinet Network Using Simatic KTP600 Basic color PN Touch Panels,” Murdoch Univ, Perth, 2013.

[62] Siemens, “SIMATIC Distributed I/O System Fail-Safe Engineering ET 200S Distributed I/O System,” 7 2013. [Online]. Available: https://cache.industry.siemens.com/dl/files/437/12490437/att_878865/v1/et200s_f_operating_manual_en-US_en-US.pdf. [Accessed 29 9 2016].

[63] Amplicon, “Process Control - What is Distributed I/O.,” 2014. [Online]. Available: https://www.amplicon.com/Process-Control/dist-io.cfm. [Accessed 6 10 2016].

[64] Siemens, “SIMATIC ET 200S distributed I/O IM151-3 PN HIGH FEATURE interface module (6ES7151-3BA22-0AB0),” 4 2007. [Online]. Available: https://cache.industry.siemens.com/dl/files/632/25385632/att_40191/v1/et200s_im151_3_pn_high_feature_manual_en-US.pdf. [Accessed 30 9 2016].

[65] Siemens, “SIMATIC ET 200S distributed I/O Digital electronic module 4DI DC24V HF (6ES7131-4BD01-0AB0) Manual,” 4 2007. [Online]. Available: file:///C:/Users/Matt/Desktop/25388101_et200s_4di_dc24v_hf_manual_en-US.pdf. [Accessed 8 10 2016].

[66] Siemens, “SIMATIC ET 200S distributed I/O Digital electronic module 4DO DC24V/0.5A HF (6ES7132-4BD00-0AB0) Manual,” 10 2009. [Online]. Available: https://cache.industry.siemens.com/dl/files/872/38661872/att_111057/v1/et200s_4do_dc24v_05a_hf_manual_en-US_en-US.pdf. [Accessed 3 10 2016].

[67] Siemens, “SIMATIC ET 200S distributed I/O Power module PM-E DC24..48V (6ES7138-4CA50-0AB0) Manual,” 4 2007. [Online]. Available: https://cache.industry.siemens.com/dl/files/985/25547985/att_825487/v1/et200s_powermodul_dc24v_48v_manual_en-US_en-US.pdf. [Accessed 6 10 2016].

[68] O. Bensaoud, “Laboratory Guide 3 (ET200S),” Murdoch Univ, Perth, 2013.

[69] OPC DataHub, “What is OPC,” 2010. [Online]. Available: http://www.opcdatahub.com/WhatIsOPC.html. [Accessed 12 8 2016].

[70] Moxa, “MGate 5102-PBM-PN Profibus Master-to-PROFINET Gateway User's Manual,” 3 2016. [Online]. Available: http://www.dynalogindia.com/wordpress/wp-

content/uploads/2015/10/MGate_5102-PBM-PN_Users_Manual_v1.pdf. [Accessed 2 10 2016].

[71] Siemens, “SIMATIC NET Industrial Ethernet Switches SCALANCE X-200 / XF-200 Operating Instructions,” 3 2009. [Online]. Available: https://www.automatyka.siemens.pl/docs/docs_ia/Switche_zarzadzalne_SCALANCE_X-200.pdf. [Accessed 1 10 2016].

[72] Siemens, “Siemens SIMATIC DP/DP Coupler Manual,” 2 2006. [Online]. Available: https://cache.industry.siemens.com/dl/files/382/1179382/att_41598/v1/dpdpk_e.pdf. [Accessed 10 10 2016].

[73] Siemens, “automation.siemens.com,” 2015. [Online]. Available: www.automation.siemens.com/.../catalogs/catalog/IK_PI_2015_en.pdf. [Accessed 6 9 2016].

[74] Scottish Qualifications Authority, “Token Passing,” 2007. [Online]. Available: http://www.sqa.org.uk/e-learning/NetTechDC02CD/page_65.htm. [Accessed 13 10 2016].

[75] J. K. Ramasamy, “SCADA System on Profibus DP,” Murdoch Univ., Perth, 2015.

[76] J. Wiggins, *Siemens HMI Touch Panel Profibus Configuration Guide,* 2015.

8.0 Appendices – List of Developed Learning Modules – Microsoft Word Document Format

The developed learning modules from this project were not included in this report due to the large quantity of material. They have been provided to the project supervisor in an electronic format. To obtain access, please contact the Murdoch University South Street Campus School of Engineering and Information Technology.

8.1 Unit Introduction

8.2 Profibus

8.2.1 Introduction

8.2.2 Siemens S7-300 PLC Master

8.2.3 Siemens HMI Touch Panel

8.2.4 Moeller easy719-DC-RC Control Relay

8.2.5 RS-485 Repeater

8.2.6 SEW Eurodrive MOVITRAC B VSD

8.2.7 Danfoss VSD

8.2.8 Siemens S7-300 PLC (Slave)

8.3 SIMATIC WinCC Realtime Professional

8.3.1 One Panel – Moeller + VSD HMIs

8.3.2 Two Panels – Process Simulation

8.3.3 Four Panels

8.3.4 Eight Panels

8.4 Profinet

8.4.1 Introduction

8.4.2 S7-1200 PLC

8.4.3 KTP600 Basic Color PM Touch Panel (HMI)

8.4.4 ET200S Distributed I/O

8.4.5 S7 OPC

8.4.6 MOXA MGate 5102-PBM-PN Gateway