A study and the evaluation of real time performance of Samancor's Profibus network

by

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Declaration

I declare that the work presented in this dissertation is my own work, except for places where references are made by index citation referencing style. The contents of this dissertation have not been submitted to any university before.

Signed: ______________________

Abstract

The field buses, and particularly the 'PROFIBUS', are currently widely used in automation systems, with the intention to automate industrial applications. It is of the utmost importance that one should understand how these systems operate, because failure to understand may result in improper applications, which can ultimately lead to intense network problems and, consequently, lead to potential catastrophic failures in industrial equipment, as well as compromising the health and safety of the people.

This research was the performance evaluation of SAMANCOR PROFIBUS network that controls the chrome manufacturing plant. The problem with the network was that it was failing intermittently. These network failures resulted in loss of production, loss of throughput, compromised quality, downtime due to reworks, high costs in energy used to rework, and equipment damage or failure.

One of the OBJECTIVES of the research was to carry out a performance evaluation of the PROFIBUS network in terms of the possible electromagnetic interference (EMI) within the plant's PLC network. This topic emanated from the network service providers that kept insisting that the network was unstable, due to possible electromagnetic interference caused by possible high voltage cables running next to the plant network cables. This assumption was without fact, and hence the research was conducted.

The QUANTITATIVE research method was used to conduct the research, where simulation of the plant network, using external parameters, were used to carry out the research. Furthermore, experiments were conducted and the physical measurements were performed on the network, where parameters derived from these measurements were used to compare the two networks. In essence, the network was tested under known configurations. The manner in which the network was simulated was that of stepping up the electrical current from the external device, and recording the response of the network. A stand-alone network rig was built and used to carry out the tests, and the results were compared with those obtained from the plant network.

Acknowledgments

Firstly, before I even start to mention anyone, I would like to thank my Lord and Saviour Jesus Christ, without whom, I would not have been able to start and conduct this research work.

Secondly, I would like to take this opportunity and appreciate my supervisor, Dr Mbuyu Sumbwanyambe from the University of South Africa, for mothering my research work. Without you, Doctor, this dissertation was not going to succeed.

To my friend and study master, Mr Malusi “Papaluja” Sibiya, who was also a student of Dr Sumbwanyambe: buddy, thank you for the time, guidance and idea-sharing that we undertook on both our research work.

I would also like to extend my greatest gratitude to Tubatse Ferrochrome for allowing me to conduct this study and research at their organisation. I really appreciate everyone who contributed to the study with both theoretical information and practical work that was undertaken. It would be inappropriate not to mention the names of my associates and friends, Mr Chris Vorster and Mr Kagiso Kekana.

Lastly, I would like to thank my wife, Thokozile Mahlangu, for making sure that the children slept early, so as to avoid disturbance during my night owl times. To you, once again, I say 'salute'.

To my parents, Mr Solly Mahlangu and Mrs Florence Mahlangu, I would love to dedicate this master’s degree to you. Thank you for everything, and God bless you.

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Abbreviations

A – Amperes/Amps

ARQ - Automated Repeat Request

AS – Automation System

BER – Bit Error

BEL – Bit Error Level

BU - Business Unit

CP- Communication Processor

CPU – Central Processing Unit

CSO –Control Systems Office

DOL – Direct Online

DP – Decentralised Peripherals

DSR – Design Science Research

ES – Engineering Station

ET – Extension

EM – Extension Module

EMI – Electrical Magnetic Interference

EMF – Electromagnetic Field

GSD – General Station Description

IDX – Industrial Data Exchange

IP- Ingress Protection

IP Address – Internet Protocol Address

I/O – Input / Output

LED – Light Emitting Diode

MAC - Media Access Control

Mbps – Megabits per second

MES – Manufacturing Engineering System

OSS – Operator System Server

OSC – Operator Server Client

OTSD - Off the Shelf Devices

PCC – Profibus Competence Centre

PLC – Programmable Logic Controller

PS – Power Supply

PSP – Pelletizing and Sintering Plant

S7 – Siemens version 7 software.

SCADA – Supervisory Control and Data Acquisition

TIA – Totally Integrated Automation

TFC – Tubatse Ferrochrome

UPS - Uninterrupted Power Supply

Glossary

Analog – A signal that is varying in nature and can be measured in a specified range.

Binary – A stream of 1s or 0s arranged to represent a specific instruction or command.

Digital – A signal that is expressed in two stages: either on or off, or a 1 or a 0.

IDLE – A condition where the powered network instrument is neither active nor disabled, but is just waiting for an instruction to execute.

Interference – An external signal that interrupts another signal and changes its form

Plant – An arrangement of electrical and mechanical machinery or equipment in an enclosed or demarcated building, arranged with the aim of manufacturing or processing minerals.

Profibus – An industrial communication protocol that stands for 'process field bus' which uses serial communication protocol.

Profinet – An industrial communication protocol that uses the Internet protocol for communication.

PCS7– A Siemens-manufactured PLC software used for industrial automation.

Simocode – An electrical motor protection device used to protect a motor and to configure the motor on the industrial network.

Software – A program used to operate computers and related devices.

CHAPTER 1: INTRODUCTION

1.1 Background

In the olden days before programmable logic controllers (PLCs) were manufactured, a means of controlling the industrial plant machinery was purely by hand. PLCs came in handy, as they substituted the physical fatigue that people encountered making the controlling system much more efficient and reliable [3].

The PLC has in fact replaced all the physical relay modules that were wired physically between devices, by introducing memory locations that are built into the PLC's input and output (I/O) modules. This memory location will input or output signals as instructed by the central processing unit (CPU) of the PLC system. Generally, these instructions are digital such as 1s or 0s or analog such as 0-10V, 0-20 mA or 4-20mA.

As the years went by and technology continued to develop, a need to expand the PLC emerged, due to the expansion of the factories and that of control systems. The PLC modules needed to be moved closer to the field devices. This was necessary, so as to reduce costs in having to run cables over very long distances – i.e. from the field to the PLC cards that were attached to the PLC's CPU via the common rack. The extension modules (EMs) were developed, and enabled the input and output modes (I/Os) of the PLC to be separated from the PLC's CPUs and reside on their own field racks. To connect these EMs with the CPUs, an industrial network system was developed using several protocols. At this stage, several protocols are available in the market, with Profibus being one of the highly used communication protocols for decentralised peripherals (DP) [4].

Generally, the pelletizing and sintering plant (PSP) at Samancor Ferrochrome is controlled by a PLC system manufactured by Siemens Automation. All the decentralised peripherals of the PLC are wired to a Profibus network protocol for communication. This is referred to as the 'plant bus', and all the engineering station PCs are included to form part of the network. Figure 1.1 shows the simplified arrangement:

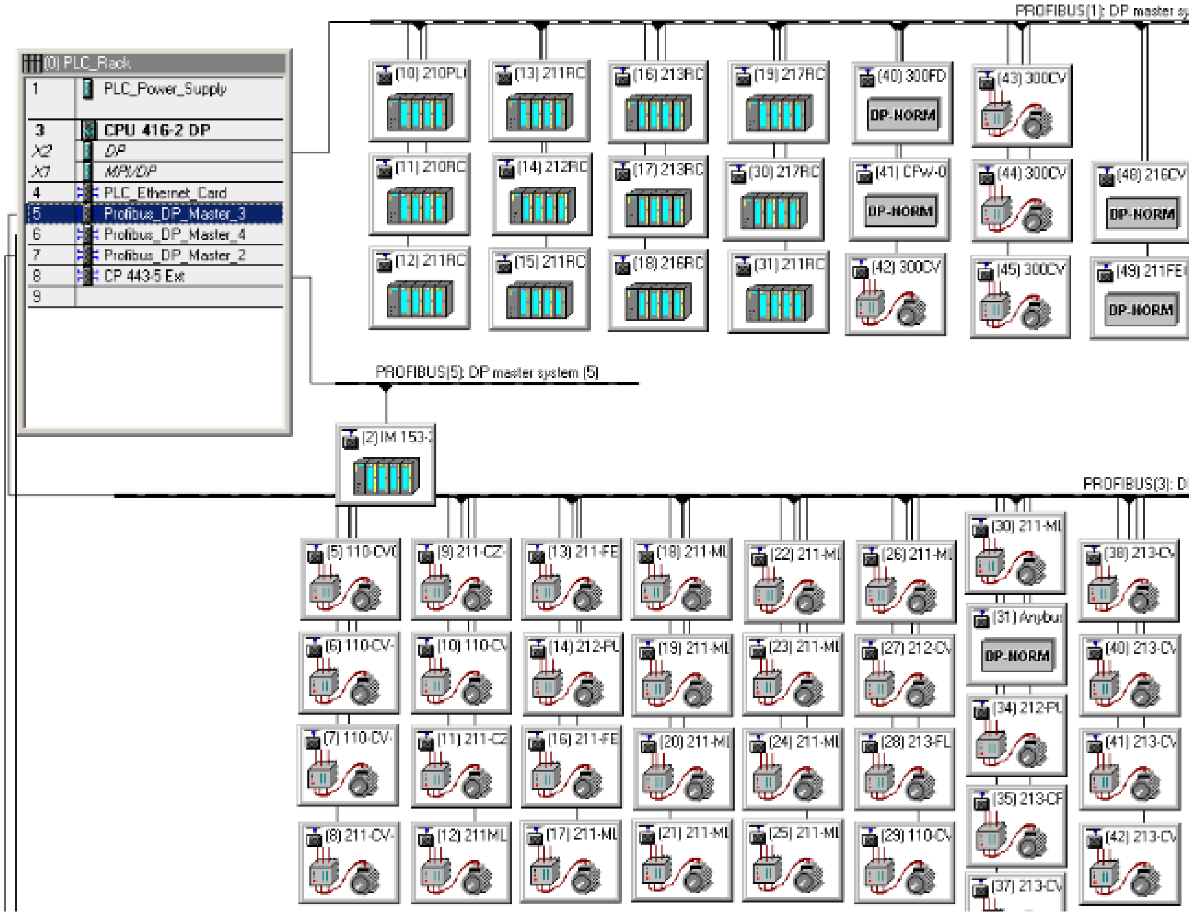


Figure 1.1: Siemens PLC hardware configuration (Tubatse plant, 2017)

As can be seen from Figure 1.1., Profibus DP master 2,3,4 and the communication processor CP443-5 Ext are individual networks. They were configured into their own Profibus network arrangement of different topologies.

To connect such a network as shown in Figure 1.1, several network topologies can be used. The most common network topologies available in the industry include, but are not limited to, star topology, bus topology, round topology and mesh topology [6]. Profibus is flexible to all the network topology arrangements mentioned above, and can also support daisy chain arrangement, but requires a terminating resistor at the end of the loop (see Figure 1.2) [7]. The letters in the blocks represents the master (M), slaves (S), repeater (R) and terminator (T):

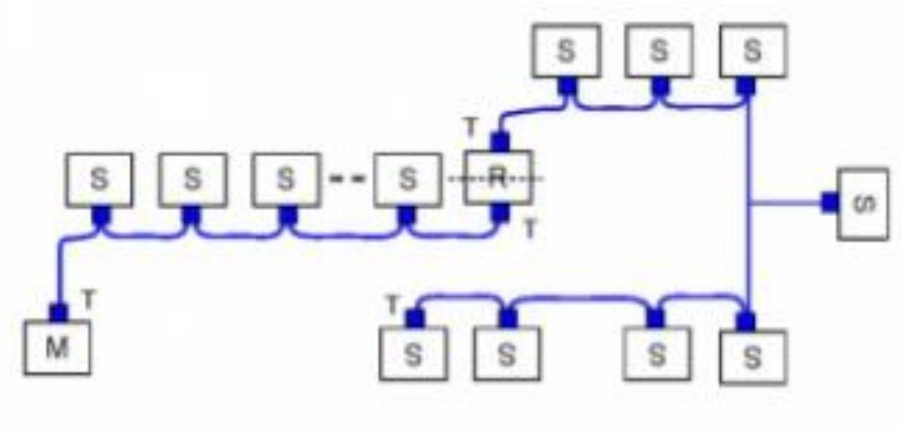


Figure 1.2: Profibus Daisy Chain Topology [5]

It is worthwhile to point out that the Profibus technology has advanced so much that almost every PLC or PC equipment manufactured has the capability of being connected or added onto the network if the need arises. It is for this reason that most of the PLC manufacturers are moving towards the technology known today as a totally integrated system (TIA) PLC arrangement (see Figure 1.3) [6]:

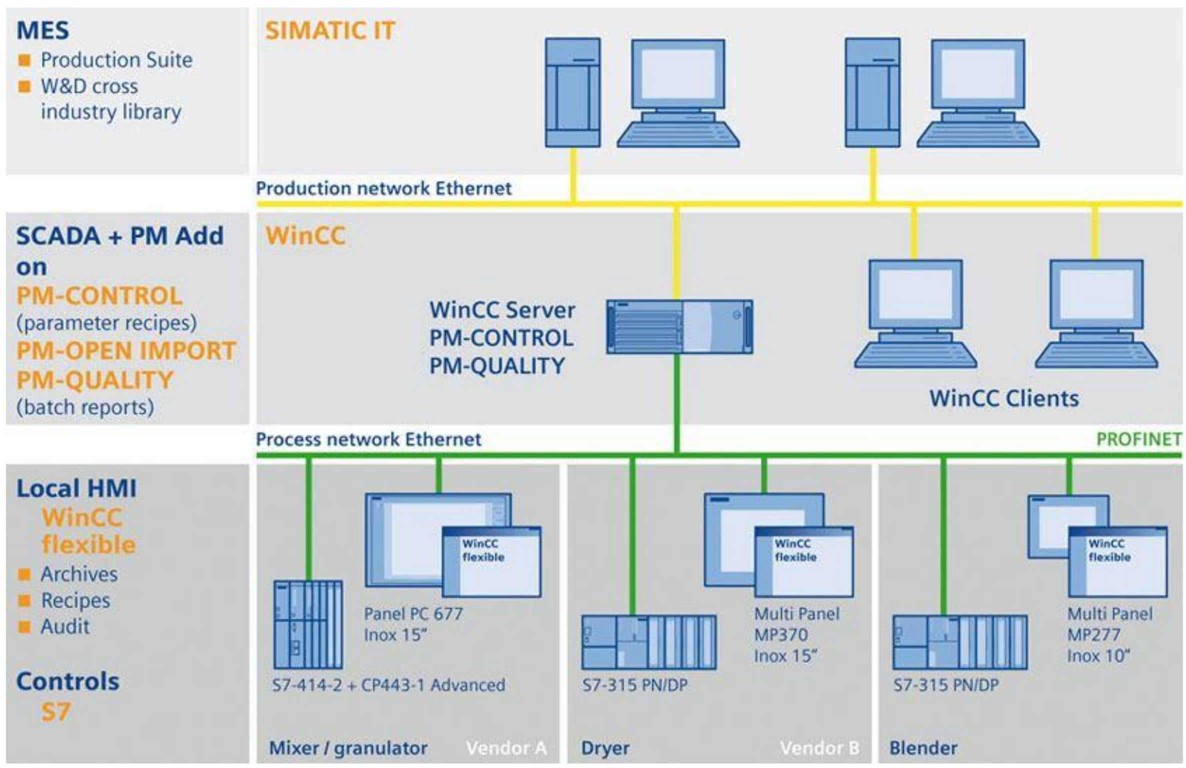


Figure 1.3: Siemens TIA system [6]

The Profibus network at the pelletizing and sintering plant (PSP) at Samancor was very unstable and very unreliable. During the time of the research, the network consisted of 29 network devices, one of which was the master and twenty-eight being the slaves. The master had the network address ‘2’ assigned to it, and the slaves also addressed from node address ‘10 to 59’ as shown in Figure 1.4, which was extracted from the Profitrace report that was conducted during the research:

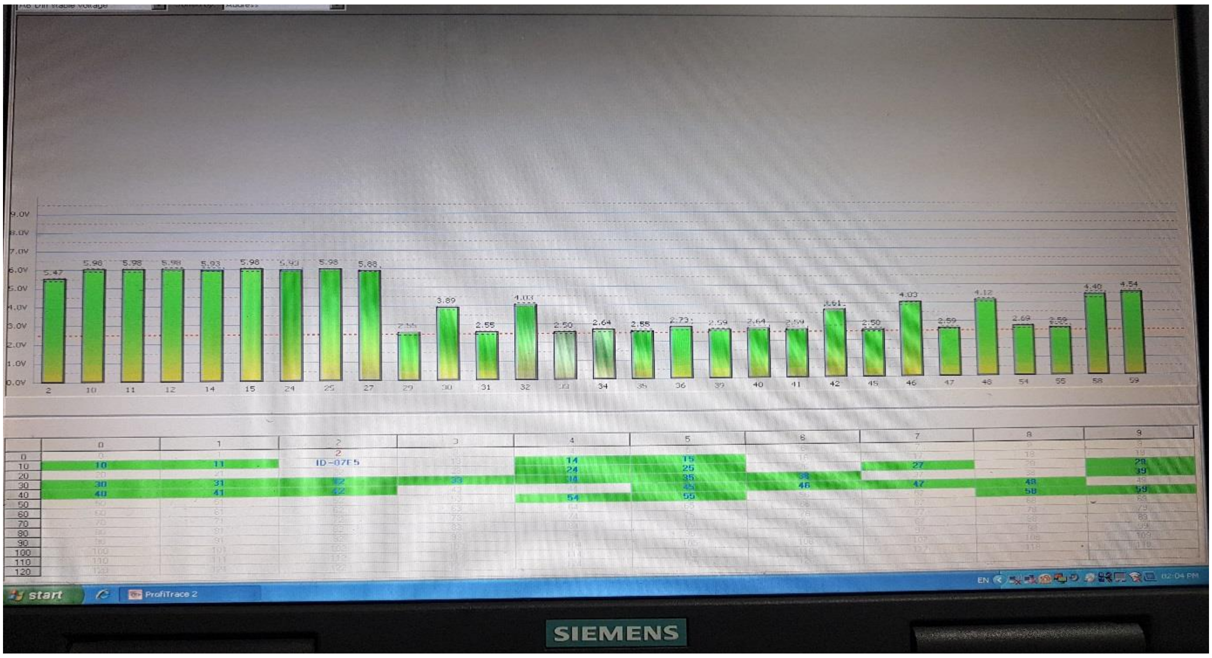


Figure 1.4: PSP Profitrace report (Tubatse plant 2017)

As can be seen in Figure 1.4, from node address No.29 to node address No.55, most of the devices were running at the threshold minimum allowable network voltage. This clearly indicated that there was a problem in the network. The live waveform of these nodes showed fluctuations on the bar graph between 2.5 volts and 7.2 volts. This were observed when high voltage cables that supply high kilowatt rated motors started drawing high current, especially during the startup of those machineries.

1.2 Problem statement

The mining of raw materials and the manufacturing of their associated products have become one of the biggest businesses around the country and the world at large. Due to the competition that these companies pose on one another, it is thus very important to produce and deliver to the customers in time. The quality of those products also has a detrimental effect on the sustainability of their businesses. If a production plant keeps on having very long downtime due to the plant not running, monthly production targets are not achieved. Customers become dissatisfied and start looking for alternative suppliers of the same product.

The instability of the network system at the PSP had a negative impact in the production throughput. At times, production targets were not achieved. The plant incurred high costs due to the reworking of the products. This was due to these network communication errors on the Profibus network. The reduced productivity affected the six furnaces upstream that depended on the production from the PSP:

1.2.1 Network instability at Samancor

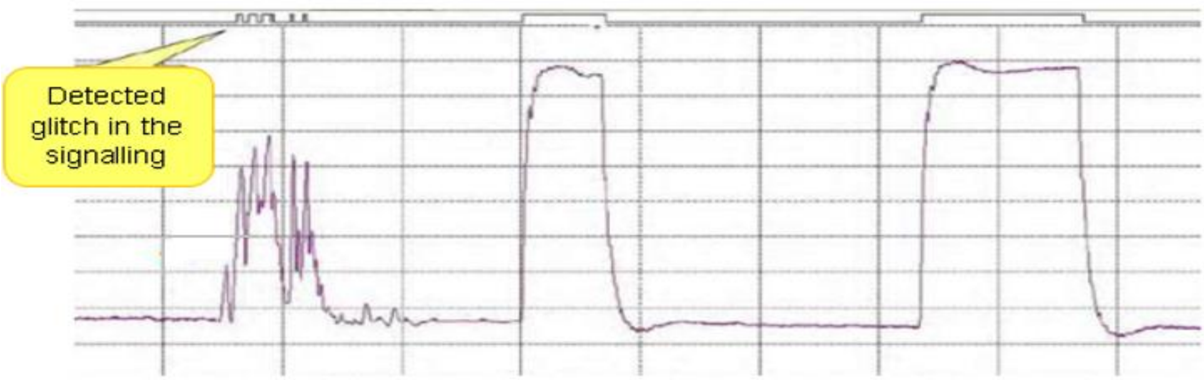
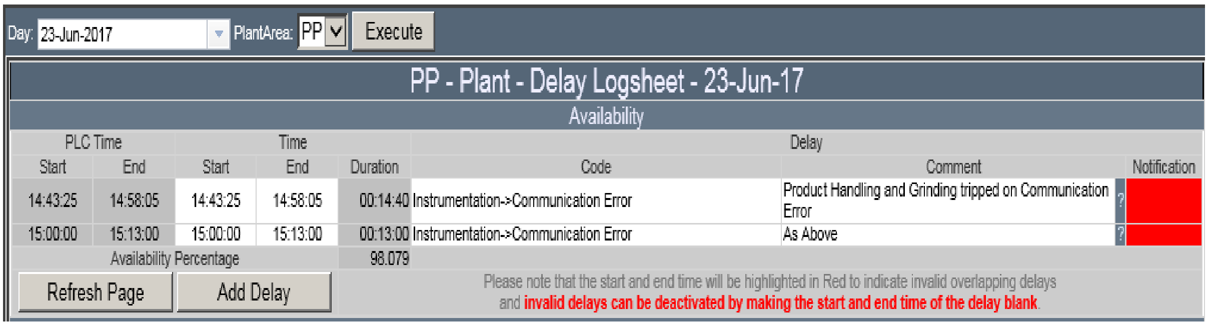


Figure 1.5: PSP Profitrace waveform (Tubatse plant, 2017)

At PSP, there is a section of the plant called the grinding section. Within the grinding section, a 3.3MW motor drives the whole system. The motor draws full load current when it is started. When this motor started running, interferences were induced into the Profibus network and led to plant failures. For example, a general report, as extracted from the MES system at PSP, showed the interruption of the plant due to interference (see delay report from the daily production shift log sheet in Figure 1.6):



Day: 23-Jun-2017 PlantArea: PP Execute

PP - Plant - Delay Logsheet - 23-Jun-17

Availability

PLC Time		Time			Delay		
Start	End	Start	End	Duration	Code	Comment	Notification
14:43:25	14:58:05	14:43:25	14:58:05	00:14:40	Instrumentation->Communication Error	Product Handling and Grinding tripped on Communication Error	
15:00:00	15:13:00	15:00:00	15:13:00	00:13:00	Instrumentation->Communication Error	As Above	
Availability Percentage				98.079			

Refresh Page Add Delay

Please note that the start and end time will be highlighted in Red to indicate invalid overlapping delays and invalid delays can be deactivated by making the start and end time of the delay blank.

Figure 1.6: Production shift log-sheet delay report (Tubatse plant, 2017)

The age of the plant, and the manner in which new network additions were done over the years, made it very difficult to do fault finding on the network. The drawings were outdated, and some devices that were added on the physical network loop were not updated on the original network drawings. Some Profibus cables were running next to high voltage electrical cables and sometimes on top of them. In some instances, some Profibus devices were supplied from different sources of power, and not from the UPS (Uninterrupted Power Supply) power which should be the common power supply to the network.

1.3 Research Questions

Given the above problem statement, this study was conducted in the attempt to address the following questions:

- What are the causes of network failure on the Samancor Profibus network?
- Are there any interferences that might be introduced into the Profibus network?
- If there are such interferences, to what degree is it interference?
- What is the performance of the network when another network cable is used on the PLC being used?
- How does the signal strength/voltage of the network compare to other stand-alone networks?

1.4 Objectives

The basic aim of this research was to determine the reasons why the network protocol (Profibus DP) at Samancor was so unstable. A thorough study and an evaluation of the network were conducted to pinpoint the reasons why there were communication failures on the Profibus. In this research, the simulation and network analysis tools were used to find solutions to these failures. The goals were as follows:

- To evaluate the performance of the network using standard testing methods to see if there are any interferences that might be introduced into the Profibus network.
- To compare different network cables that can be used on Profibus network PLC.
- To measure if the signal strength/voltage of the network is sufficient.
- To test and simulate the network using parameters in objectives 1 and 2 and compare them with the physical performance of the network.

1.5 The research method/design

The quantitative research methodology, particularly simulation and experimental analysis of the network, was used where the best practices regarding Profibus network performance were compared and evaluated. The research followed the research process as illustrated in the following sequence diagram:

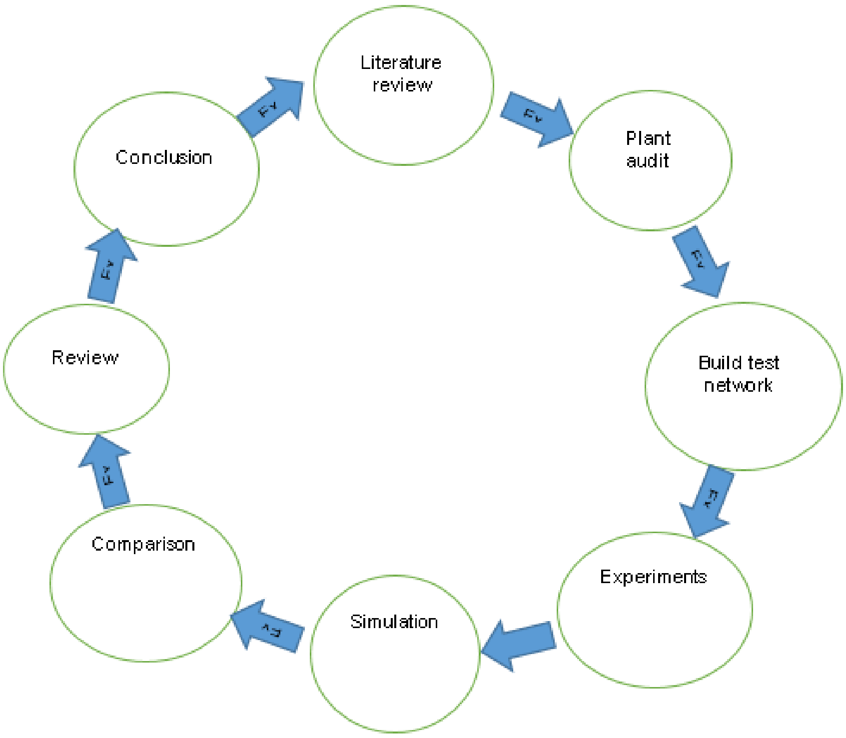


Figure 1.7: The research process to be followed

The sequence, as shown in Figure 1.7, involved two separate Profibus networks (i.e. the live network at PSP and the stand-alone network – built for testing purposes). These networks were compared to determine the behaviour of each network when exposed to known configurations. The plant network was also audited to determine its health status and to check the deviation to the installation standards. As can be seen, seven steps were followed before conclusions were given. Profibus literature was reviewed by gathering information on the Profibus and network communication. The second step was to carry out the Profibus installation standard audit and the software configuration audit of the industrial network, and capture the results on the checklist.

Step no.3 was to build a stand-alone Profibus network where experiments and tests were conducted. Simulation and/or injection of noise interference into the stand-alone network was carried out by using a welding machine while welding at different welding currents. The results from the attained values were interpreted and compared.

In essence, this study followed a quantitative approach, but, in particular, design science research (DSR) methodology. The research design involved identifying the problem area, and conducting a literature survey of the knowledge base in order to come up with the direction that needed to be followed. The literature survey and the experiments conducted consolidated the research. The study addressed four objectives, as outlined in Section 1.4 of this chapter. In essence, Figure 1.8 and Table 1.1 gave a tentative relationship between the problem area, the reviewed literature, and how to achieve the objectives:

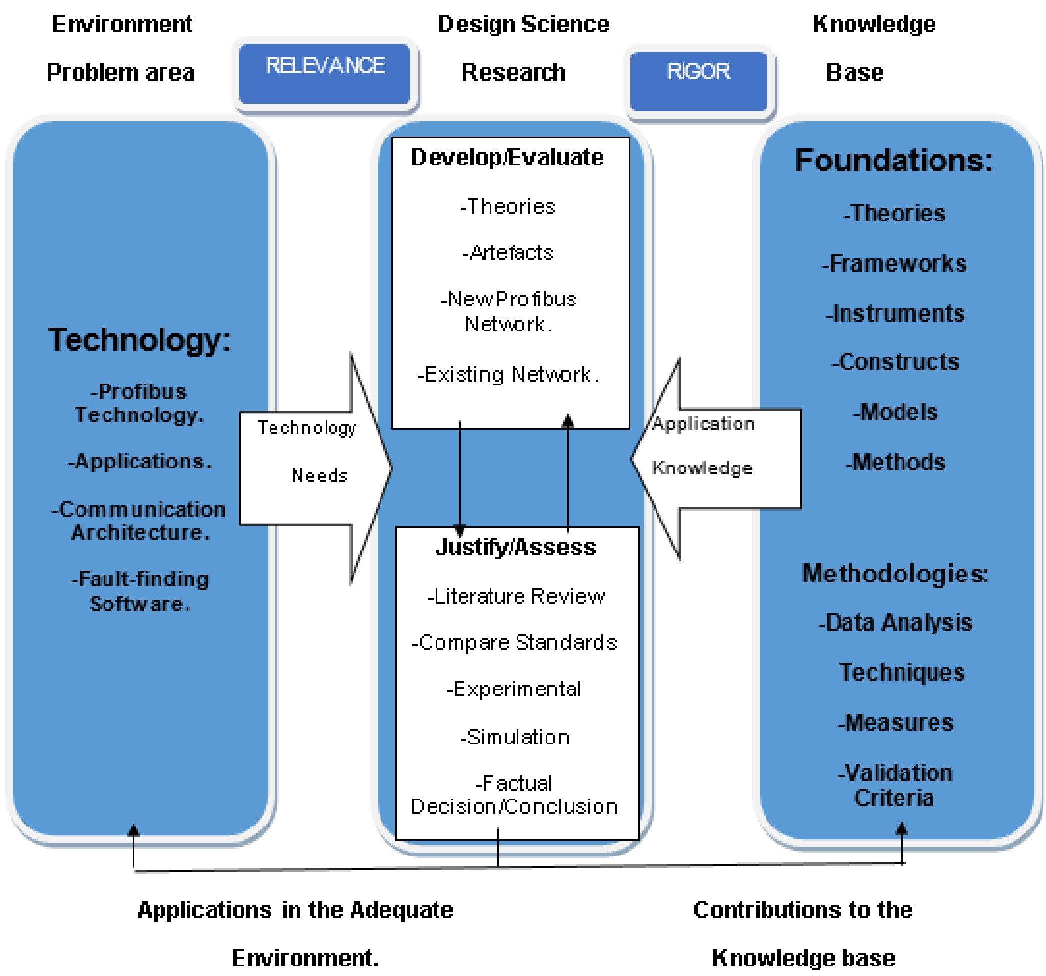


Figure 1.8: The research design to be followed in this study [7]

This research employed well-established methods to support the developments, justifications and the evaluations of activities that took place. Table 1.1 summarises the research methodology with respect to the research questions, the objectives, and the method, that were used to achieve the objectives:

Table 1.1: Summary of research methodology

	Research Question	**Objective**	**Method**
1	What are the causes of network failure on the Samancor Profibus network?	To evaluate the performance of the network using standard testing methods to see if there are any interferences that might be introduced into the Profibus network.	Build a Profibus network on a rig and use software tools to determine the characteristics of the network without faults. Then introduce/simulate interference at different intervals, and evaluate the reaction of the network.
2	Are there any interferences that might be introduced into the Profibus network?	To compare different network cables that can be used on Profibus network PLC.	Evaluate the network's state using the Profibus testing equipment, and analyse and tabulate the findings.
3	If there are such interferences, to what degree is it interference?	To measure if the signal strength/voltage of the network is sufficient.	Use analysis on point 2, above, to determine the strength on the current Profibus network. Profitrace tool will be used to measure the voltage strengths.

4	What is the performance of the network when another network cable is used on the PLC being used?	To test and simulate the network using parameters in objectives 1 and 2 and compare with the physical performance of the network.	Use a welding machine to induce high voltages next to the Profibus cables. This induction of voltage will be done at different current magnitudes.
5	How does the signal strength/voltage of the network compare to other stand-alone networks?		Compare the values of the two networks and come to some sort of conclusion.

1.6 Significance of the study

The results of the study gives a thorough understanding about interferences that might be induced into the Profibus network. It also closes the gap about common network interference that normally arise on any Profibus network installation. The research allows any network technician to distinguish the difference types of the industrial network communication protocols that are available, and their differences.

This study has significance in a way that it provides stability and improves the availability of the plant, due to applying the learning from its content. A stable system will ensure that the department section has a reliable network system and, consequently, a reliable plant. This will automatically result in a smooth operation of machinery.

The study further ensures that injuries, fatalities and damage to property or equipment are reduced dramatically if machineries are running smooth. Quality products get manufactured and revenue is realised. Employees also benefit and enjoy operating the plant, and bonuses are possible. The outcome of this study enables most companies to invest in “optimizing the network”, because the owners will see returns and the value that a reliable system brings, in a form of good revenue.

1.7 Dissertation roadmap

The research outline for this dissertation is as follows:

Chapter 1 gave a background to the study, the problem statement and the study objectives.

Chapter 2 presents a literature review on the research topic.

Chapter 3 will present the methodology used in this study.

Chapter 4 will present, discuss and analysed the results.

Chapter 5 will presented the conclusion, future works and recommendations.

CHAPTER 2: OVERVIEW OF PLC SYSTEMS

2.1 Introduction

Understanding an automation system in full depth enables one to make rational decisions in solving problems and in the optimisation of the system itself. One can also make comprehensive recommendations because one already knows how the system “should be”. One therefore need to think systematically to approach inherent or induced problems within a system.

Richmond [8] defines system thinking as the “art and science of making reliable interpretations about the behaviour by developing an increasingly deep understanding of underlying arrangements”. In this section of the report, literature regarding Samancor’s automation network is reviewed. This literature review focuses particularly on automation at Samancor Ferrochrome, types of PLCs used, the Profibus system, the current state of the system, how the system was expected to be, the installation standards, the best practices and recommendations, and, lastly, the related work. The information gathered from the literature review in this chapter is used in the formulation of the methodology chapter, and forms a prototype for Chapter 3 (the methodology chapter).

2.2 Background of automation at Samancor Ferrochrome

Samancor Ferrochrome in the Tubatse region has opted for the centralised control system office (CSO) where all the plants are controlled from a central point. It currently comprises two engineering stations (ES), where either one can be used to connect to any of the plants for programming, fault finding and control of the plant equipment.

There are two servers: operator system server 1, and operator system server 2 (OS1 and OS2, respectively) that divide the plant into two sections and also avoid a single point of failure. In all different plants, there are clients servers that are used by plant operators to operate and control the respective plants devices. Figure 2.1 illustrates the setup in simplicity:

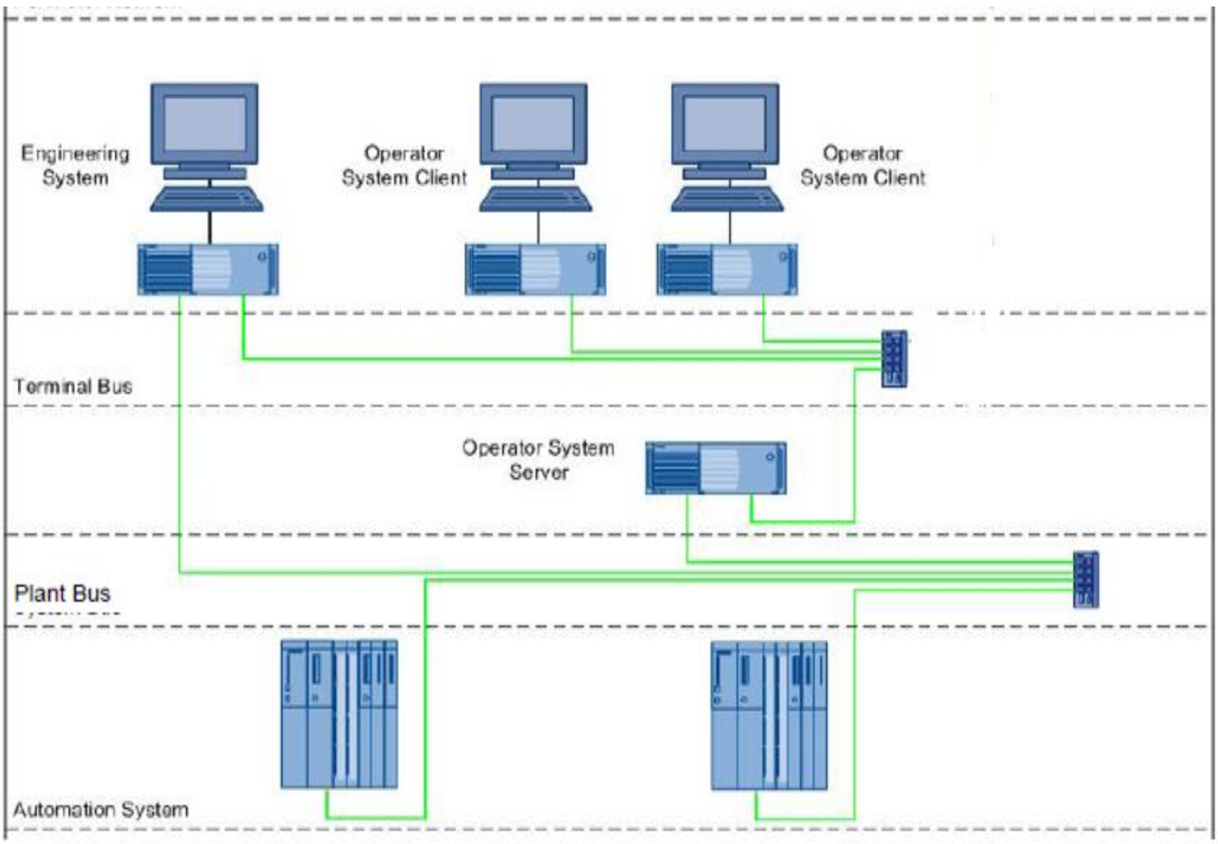


Figure 2.1: Samancor's client/server network arrangement (Tubatse plant, 2017)

As can be seen, both the engineering system and the operator system clients are connected to the operator system server through a network switch. The automation system (i.e. PLCs) are connected to the server through their own network switches. This system applies to one department only. The rest of the departments are also configured in the same way, so as to interconnect everything together. Network switches known as scalence are used in the automation network, and everything is wired up using profinet protocol. Each switch is therefore given its own IP address and will typically will have its own MAC address.

The Samancor automation network is monitored at all times by software supplied by Siemens automation called "sinema". The server (see Figure 2.2) shows the configuration of the whole network and the topology as displayed in real time:

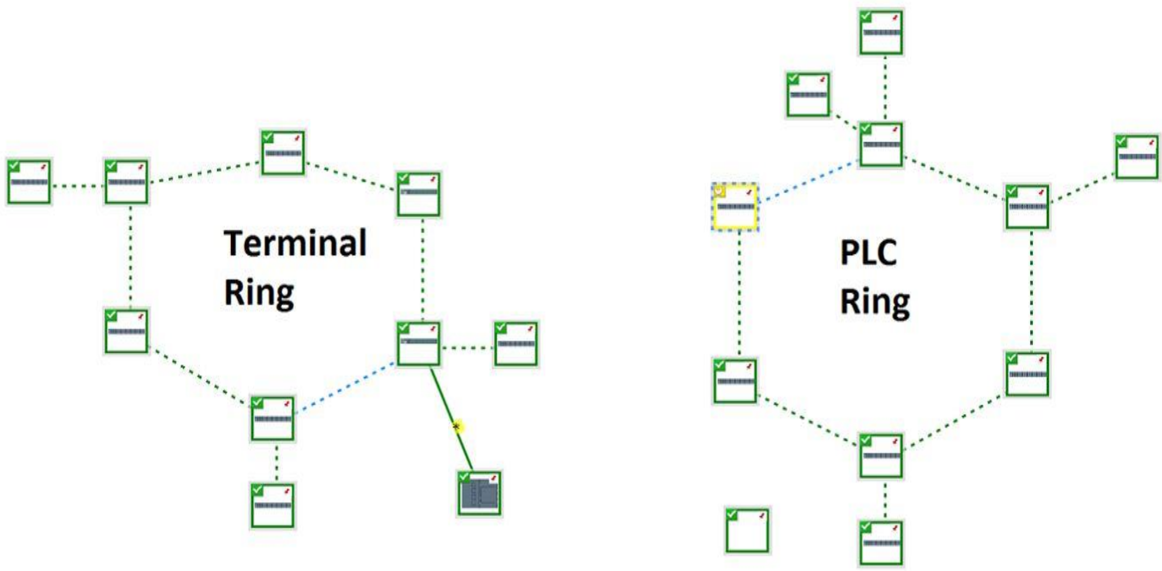


Figure 2.2: Sinema network topology (Tubatse plant, 2017)

As can be seen in Figure 2.2, a real time demonstration of the network is displayed. The yellow colour of the switch demonstrates that the particular switch needs maintenance. The green colour indicates that the switch is healthy and can be reached from the controlling device.

Referring back to Figure 2.1, it can be seen that there are two network communication busses. These are the terminal bus and the plant bus. The terminal bus connects all the operator station clients and the engineering station with the server, while the plant bus connects the automation system with the server.

The automation system, the PLC, connects with the field devices through remote I/O stations known as the EM, which is short for 'extension module'. The EM-stations are connected to each other by a communication protocol known as the Profibus DP. This media is typically a purple cable that aids communication between the field devices by connecting two wires (red and green) in a certain configuration.

2.3 An overview of PLCs

Simatic (Siemens) hardware and software have been standardised throughout Samancor, and controlled at the central office called the control systems office (CSO). The Simatic 400 series is used as the main PLC, and the 300 series is used to connect the field devices.

The Siemens PLC typically consists of the following:

400 Series (Main Control)

i. PS – Power Supply module
ii. CPU – Central Processing Unit
iii. CP – Communication Processor

300 Series (Extension Modules)

i. PS – Power Supply Module
ii. ET200M/S – Extension Module
iii. IM Module – Interface Module
iv. I/O module – Digital inputs or outputs and analog inputs and outputs

The main control unit is connected to the extension modules through the Profibus communication protocol. The connection between the CP cards and the ET stations is referred to as DP. Figure 2.3 shows Profibus DP1, DP2, DP3, DP4 and DP5 lines connected to the respective CP cards:

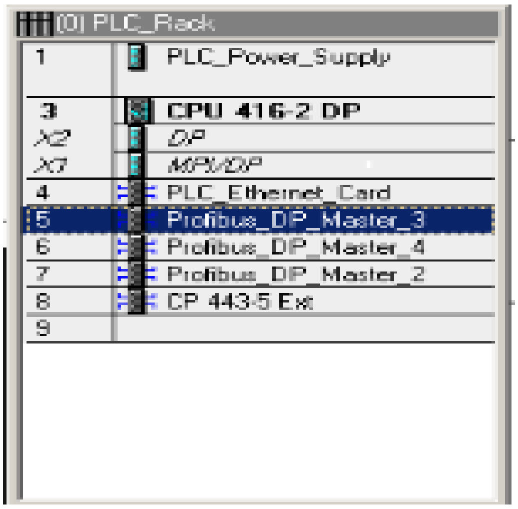


Figure 2.3: Siemens PLC hardware configuration (Tubatse plant, 2017)

The decentralised peripherals (DP) indicate a separate Profibus network with their own network nodes which have their own address for identification and communication. The CPU will normally be placed away in the control station and all decentralised I/Os in the field. The cabinet that houses the field I/Os is referred to as ET-stations where ET stands for extension module. The ET-stations are then connected to the main CPU using the Profibus cable, and the Profibus network is created as a result. The manner through which these ETs are connected is referred to as network topology.

Decentralised I/Os have advantages such as saving money through less cable usage, saving time because the wiring is neither complicated nor bulky, making housekeeping easy and maintainable, as more network devices can be added without worrying about space. Lastly, decentralised I/Os have no single point of failure, because if an ET-station fails, only that specific ET-station will be in error mode.

Regardless of the advantages, there are a few drawbacks, as follows:

- Networks knowledge is limited and might require specialised training.
- Ingress protection (IP-rating) must be ensured so that the devices don't fail. (i.e. ET-stations might be located at extreme conditions, and must be guarded against whatever the situation might be).
- A single damage to the network cable might bring down the whole network.

2.4 Profibus System

Profibus DP [9] is one of the most commonly used networks in industrial automation. The introduction of this type of network arose when the PLC I/O became too cumbersome, such that the wiring was too much. The PLC was then separated and I/Os were moved or decentralised to the location next to the remote devices.

By decentralising the PLC's I/O, a great deal of cost has been reduced in the amount of wiring that was used. Generally, instead of using thousands of copper cables, only a single Profibus cable was used; for example, Figure 2.4 illustrates the statement. Comparatively, as can be seen in Figure 2.4, the wiring with Profibus cable uses less wiring as compared to the traditional field wiring:

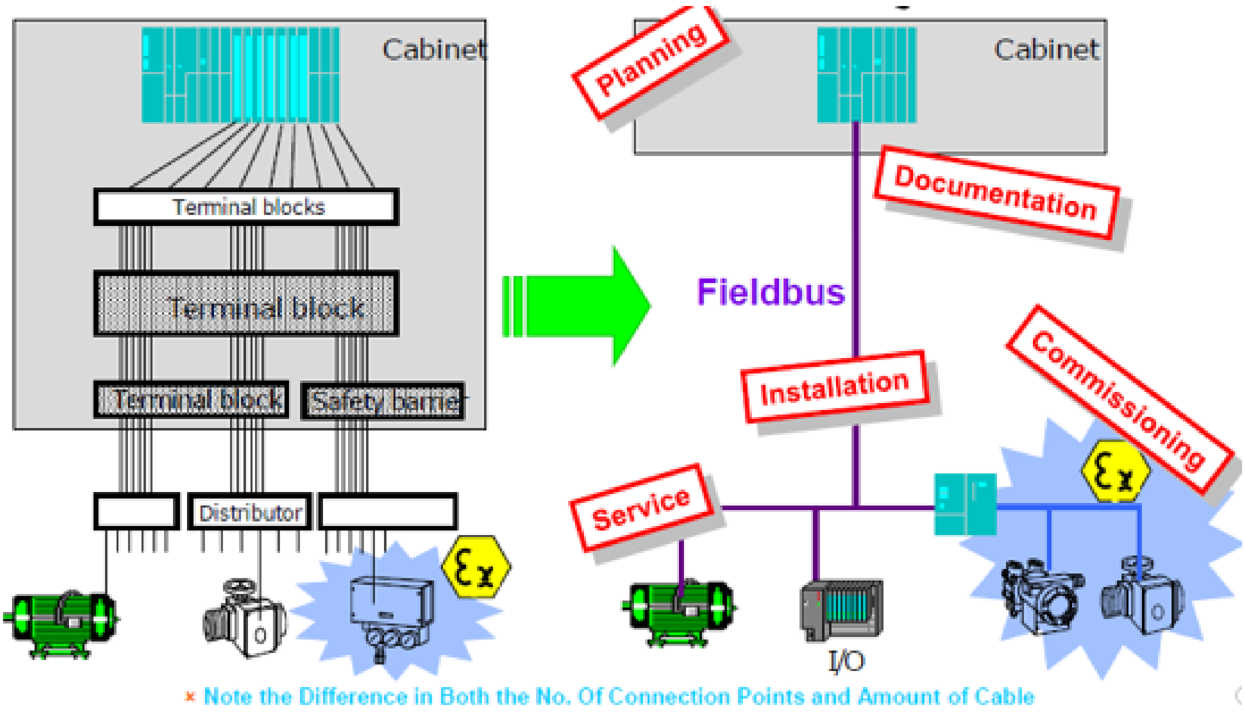


Figure 2.4: Traditional field wiring versus fieldbus [10]

Profibus DP [10] is a single purple cable with two wires inside. The wires are green and red in colour and the system works on the principle of serial communication that uses the RS485 communication protocol. The red one is the positive terminal and the green one is the negative terminal. The two wires are surrounded by a thick white insulation which is overall wrapped by a silver screening cable. The outside purple cover surrounds the screen cable (see Figure 2.5):

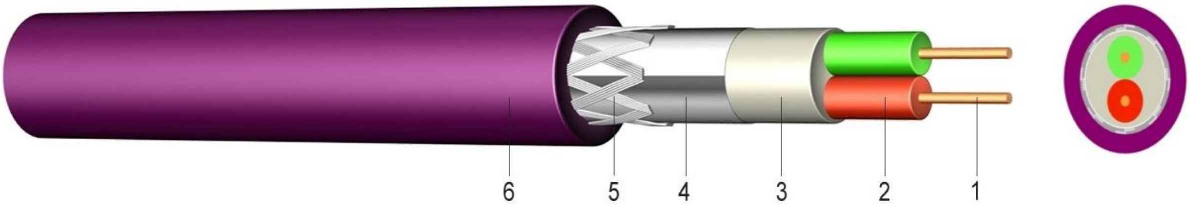


Figure 2.5: Profibus cable [11]

The numbering in Figure 2.5 is as follows: (1) represents the copper conductor for the red wire, (2) is the insulation of the red wire, (3) is the thick white insulator, (4) is the aluminium foil, (5) is the screen cable and (6) is the outer purple insulator/sheeting.

A network is formed by connecting the network devices in a certain fashion called 'topology'. In the Profibus system, common network topologies are available and include, but are not limited to, star topology, bus topology, round topology and mesh topology. At the end of each Profibus DP network, there must always be a terminating resistor which will either be inside the D9 Profibus connector, or on a dedicated Profibus active terminator. Most of the Profibus devices are built to support the termination function on them. Normally, this function is achieved by manually switching on a switch of the terminating resister plug or activating a dip switch to terminate a network. The two figures (i.e. Figure 2.6 and Figure 2.7) show the built-in terminator and the active terminator, respectively:

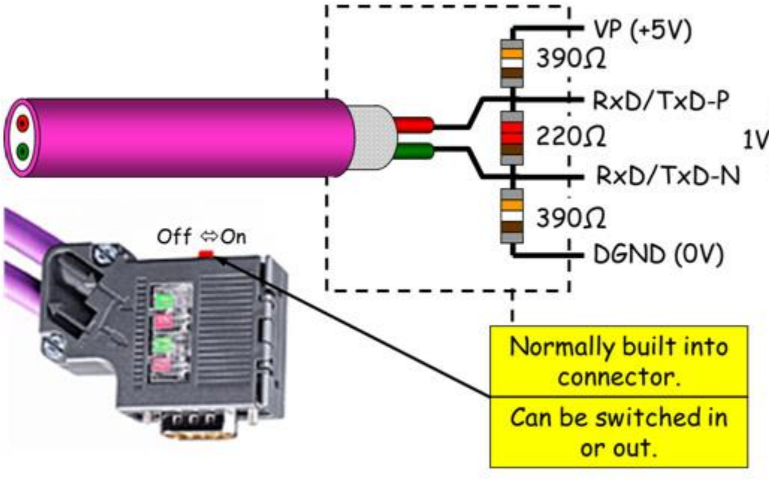


Figure 2.6: D9 built-in Profibus terminator [5]

Figure 2.7: Active Profibus terminator [6]

Figure 2.6 shows a D9 Profibus connector where the termination can be switched ON if the network ends on that connection. If this is the case, there will only be one Profibus cable (i.e. incoming cable) on the plug. The termination switch can also be used during fault finding, to separate the network temporary and be switched OFF once testing is done. This will be the case where two Profibus cables are connected to the DP connector.

Figure 2.7 also illustrates an active Profibus terminator where the end of the Profibus network can be connected to P1 and P2 connectors. The connector at the bottom is used to power the active terminator ON and the D9 connector on the terminator is used to connect an external diagnostic tool or a laptop. This is used normally during fault finding.

A clearer demonstration of how the wiring would typically be comprised of, is represented In Figure 2.8. In the figure, three network devices/nodes are indicated as “Device” on a light green background, the terminating resistors with the known resistances are shown in navy blue, and the Profibus leads (red and green) are shown as well. As can be seen, the terminating resistors are applied at the beginning and the end of the network loop:

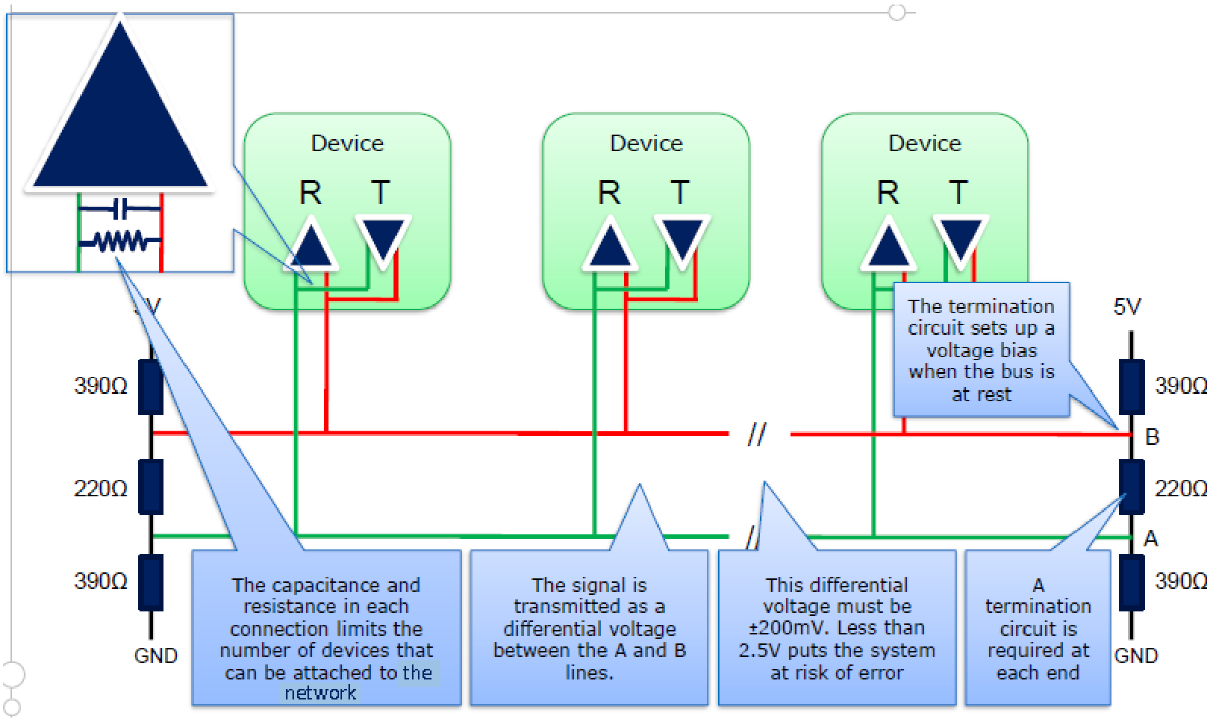


Figure 2.8: Profibus cable, devices and termination [7]

The Profibus network works on a typical RS485 principle to aid communication. This is referred to as a multi-point interface [12]. The CPU is normally the master and the rest of the network nodes are the slaves, but it also happens that other slaves can become a master to other slaves. The process field bus network functions at a loop power of 5 volts. Networks with voltage strength of less than 2.5 volts will not function effectively, and may create failures that may lead to disaster.

2.4.1 Profibus DP versions and functions

In this report, three DP versions of the Profibus were researched, and they differ in functionality. The versions are DPV0, DPV1 and DPV2 [13]:

Table 2.1: Functionality of DP versions

DPV0	• Cyclic Data Exchange Between Master and Slave • Diagnostic Reporting
DPV1	• Cyclic Data Exchange Between Master and Slave • Alarm handling
DPV2	• Deterministic Cycle-Time mode • Data Exchange Broadcast • Clock Synchronisation and Time Stamp • Upload and Download

Note: Node addresses assigned to network devices can be reserved to be used at specific addresses based on the DP version of the software being used [14]**.**

2.4.2 Profibus DP- protocol positioning

Networks can have up to 127 stations (masters + slaves). There may be more than one master, but at least one master is required for the network to operate [15]. The master is referred to as the active station, with the slave being the passive one. In a Profibus network, there are positions that are reserved when assigning numbers to the network nodes. Node address 0 is reserved for the programming device (i.e. laptop loaded with Profibus software or any Profibus configuration tool). Node addresses 1 and 2 are normally for the master station (i.e. CPU (central processing unit) of the PLC). But it can be located anywhere between 1 and 125, depending on the programmer’s choice. Slaves can also be addressed anywhere between node address 1 to 125). Node address 126 is reserved for the OTSD (off the shelf devices). Node address 127 is for multicasting (broadcast). This are messages that goes to all devices. Node addresses can be addressed by using binary dip switches, rotary switches, an external programming device, or a special “set address” bus command (see Figure 2.9):

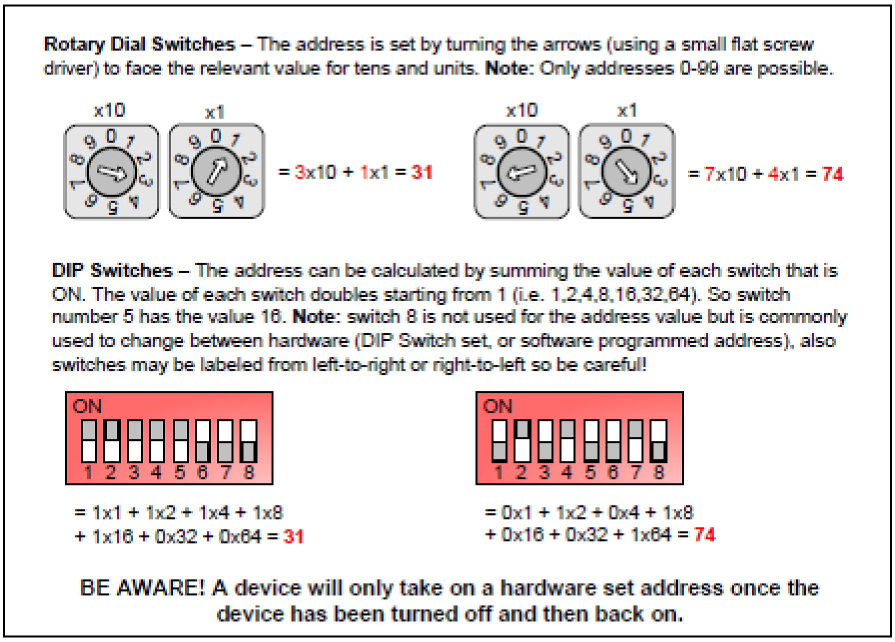


Figure 2.9: Assigning Profibus node addresses [16]

Devices such as repeaters and terminating resistors are not assigned a node address. Until a request comes from the master, the slave will remain silent (see Figure 2.10):

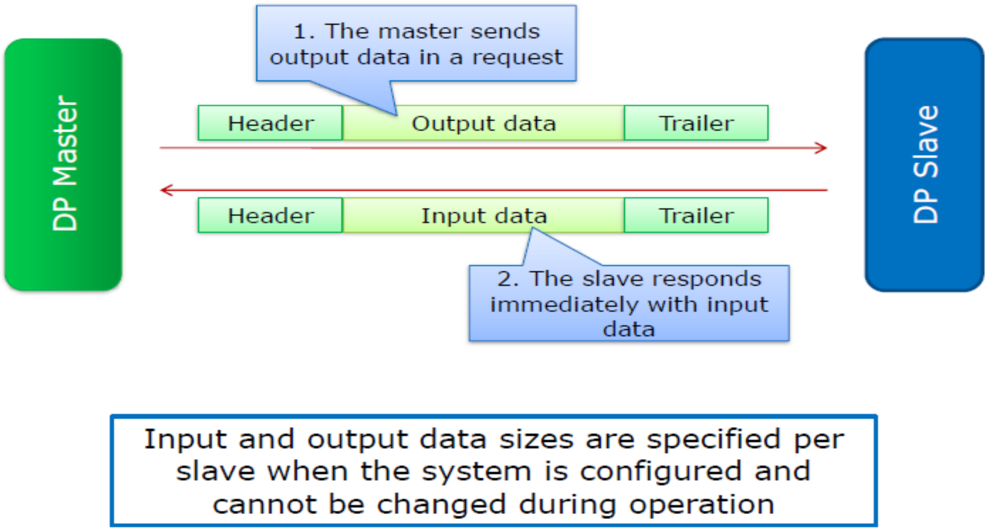


Figure 2.10: Master-slave two-way stream [17]

As can be seen in Figure 2.10, the master requests an action or data from the slave. The slave responds with, an acknowledgement or the requested data. Requests sent over the network are categorised into Class 1 and Class 2 Functions. Requests can also be combined into Class 1 and Class 2 functions. A master can control slaves and, in turn, be controlled by other slaves. Messages sent over the network are in a packet format. There can only be 244 bytes polled per session. A system with only one master is called a **mono-master** and it works in a polling fashion (i.e. one request and one reply at a time). A system with multiple masters works on a “token ring” fashion. (i.e. the master that has a “token” will generate requests and pass the “token” to the next master after its cycle has elapsed. This is illustrated in Figure 2.11:

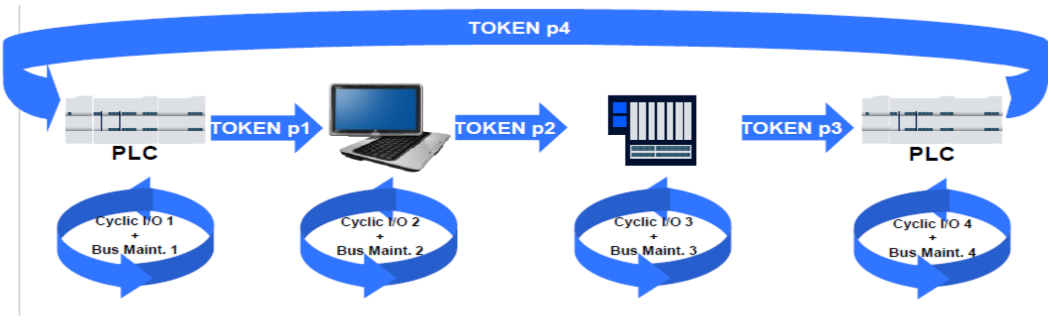


Figure 2.11: Token passing [18]

For Master 1: T_{RR} = Cyclic I/O 2 + Cyclic I/O 5 + Cyclic I/O 4 + Bus Maint.1 + Bus Maint.2 + Bus Maint.3 + Bus Maint.4 + Token p2 + Token p3 + Token P4.
Evidently, the same can be set up for the other masters.

2.4.3 Configuring the Profibus system

The systems programmer [19] needs to understand how data is processed in the Profibus configuration. This includes, but is not limited to the network speed, and type of GSD (general station description) file to be used. There are certain procedural functionalities that need to be done when configuring the Profibus system. These procedural functionalities include connecting the configuration tool, selecting and assigning the correct node address, finding the correct GSD file for each device, selecting the correct modules for data transfer, selecting device parameters and selecting module parameters:

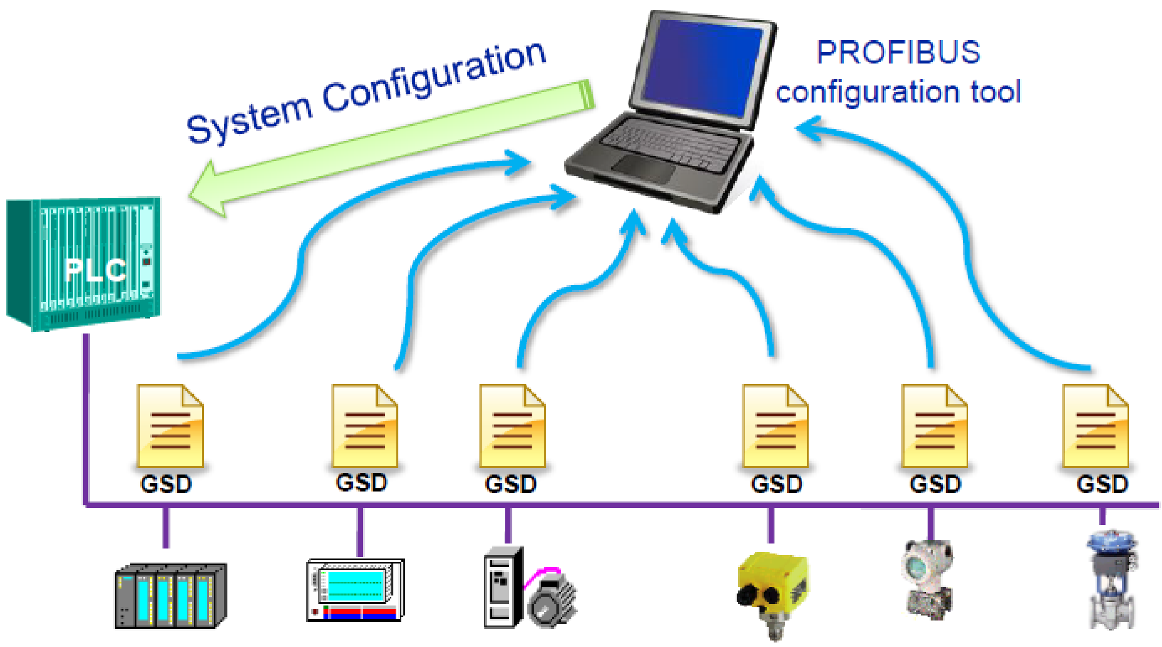


Figure 2.12: Configuring a Profibus system [19]

2.4.4 Profitrace

Every network needs maintenance to ensure reliability and good performance at all times. If one has a Profibus system, one will need a tool to monitor and troubleshoot the system. Profitrace is a troubleshooting kit that is capable of fulfilling those needs. Profitrace can monitor the live list, network statistics, power status, redundant status, termination status, lost devices, syncs, retries, duplication and channel number [20].

Besides monitoring, Profitrace can also be set up such that it can set traps and record the behaviour of the network. The information can then be viewed and analysed at a later stage. Live List is a matrix that continuously lists all the available devices. It directly make visible which devices are 'troublemakers'. With different background colours the status of the devices is displayed. Plug in anywhere in the network. Green: device is in data exchange; yellow: device is lost (check connections); red: parameter fault (wrong GSD or Address); purple: configuration fault (wrong modules); no colour: not in data exchange; red Number: master device [20].

The Profitrace tool also indicates the condition or state of the network. The software demonstrates this condition by an RGO (Red, Green, and Orange) light which is equivalent to anywhere between 0% and 100% condition of a healthy network. Red will indicate that the network is not healthy. Green will indicate a healthy Profibus network and yellow will indicate anything between healthy and poor Profibus network state or condition.

2.5 Expected network system

The screenshot of a healthy Profibus network is shown in Figure 2.13. This was extracted from the Profitrace diagnostic tool when the plant was on “IDLE” mode. As soon as the plant was started, the image changed as shown in Figure 1.4 in the previous chapter:

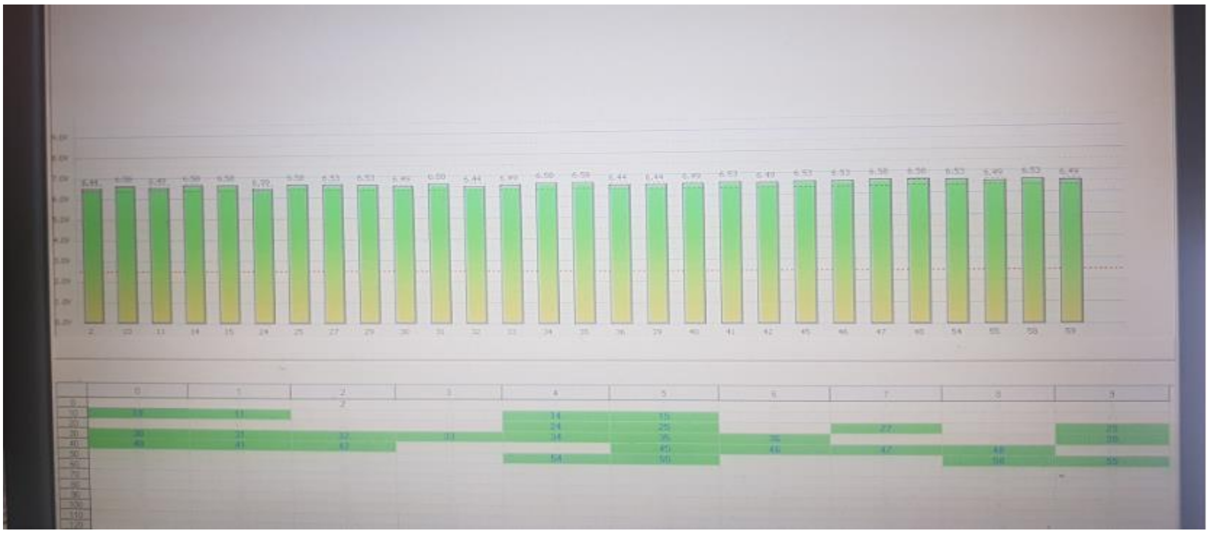


Figure 2.13: Expected network stability (Tubatse plant, 2017)

Figure 2.13 is the expected status or condition of the PSP Profibus network when the system is online and running at full capacity. Characteristics such as this shows that the plant is in full operation. Fluctuations in the bar graph will indicate an unstable system, and will indicate that there are problems within such a particular network node. Typical problems include but are not limited to reflections or interference, syncs, retries and bad termination or resistor.

The Profibus network should always be designed and installed to meet the basic rules of Profibus installation as described in the PCCSA (Profibus Competence Centre South Africa) and IDX (industrial data exchange), which is as follows [18]: the minimum cable length between network devices must not be less than 1m. Do not exceed the maximum segment length of 1000M. A repeater should be installed at every 100m of the Profibus cable. Do not bend the Profibus cable (you will pay a high price for this). Install a terminating resistor at the end of the Profibus network. Ensure that the beginning and the end of the Profibus network is terminated.

[18] Do not duplicate node addresses in the field and also in the configuration device. Do not run Profibus cable next to high voltage cables. Do not run Profibus cable perpendicular to high voltage cables. Ensure that the shield of the Profibus cable is connected to earth. Use profi-hubs to isolate noise and to avoid single point of failure. Use fibre optic technology in conjunction with Profibus for very long distance applications and when running network cables next to EMC (electromagnetic coil) devices, for noise avoidance. Ensure that Profibus cable is fitted properly into profi-plugs, and that earth/shielding is not exposed. Use correct stripping tools for stripping-off Profibus cable. Enforce correct IP installation in harsh areas.

2.8 Related work

A variety of research has been conducted by many researchers with regard to noise in the communication system. Moffitt [23] recently conducted an initial noise test setup to determine noise that can be induced in a cable. However, there were issues regarding the type of filtering used for noise measurement, the time range and measurement floor that is accepted, and a technique in which multi-drop devices can be tested that are still unclear. Graber [24] from Pepperl and Fuchs did a study of noise in process automation, and also the measurement of noise tolerance; however, the question of "handling of impulse noise events, power supply noise sources and continuous noise immunity" still stays open. The aim [24] was to try and determine how much noise can be tolerated in an industrial communication network. Felser [25] conducted a study about the quality of Profibus installation. The aim of [25] study was to improve the quality of Profibus-DP installation and to derive ways in which transmission errors can be measured. [25], study demonstrated that transmissions errors within the Profibus-DP system can be detected and corrected by a mechanism called the automated repeat request (ARQ).

In [26], a member of the CFI panel of the IEEE 802.3 Ethernet Working Group discussed the different industrial communication cables used in the market. The contribution was to establish the best communication cable for any factory, process and batch automation. The study showed that industrial networking has an annual growth of 7%, which is about 58% off fieldbus that is on high demand for industrial communication. Carvalho and Portugal [27] conducted an experimental study to analyse the outage time that a Profibus network can take to recover from a faulty mode. [27], evaluation was focused on (i) the system outage time, (ii) the station outage time, and (iii) the bus cycle time, when variables such as BER (bit error rate) and BEL (bit error length) are altered. It was then discovered that the Profibus network does get affected by the external noisy environment but it couldn’t be quantified at how much of interference acceptable.

Others, such as Vasques, Hammer, Alves, Tovar, and Rother [28], conducted a study of "[r]eal-time communications over hybrid wired/wireless Profibus-based networks" in 2002. The intention of [28] was to determine the wireless capabilities of the Profibus network. They were able to propose a wireless system that can be wired or added onto the wired Profibus network and be able to communicate wirelessly with flow devices at real time if possible. In [29], Chen, Song and Liu conducted a study of communicating with instruments in the automation system using Profibus, titled their research “The developmental design of the intelligent slave station based on the Profibus-DP fieldbus".

Peng, Li, Zhang, Huang and Bao [30] conducted a study in 2009, in Xiamen, China, and titled it “Analysis and research on the real-time performance of Profibus fieldbus” as compared to other network protocols. Their research was focused on the performance of a single-master system. It was concluded from their research that Profibus is a type of definite network in industrial network communication. Another study, conducted by Tovar and Vasques [31], was titled “Real-time fieldbus communications using Profibus networks”. This was aimed at discovering ways of how to use Profibus fieldbus networks to support real-time industrial communications. [31], study concluded that only one token message at a time can be processed at the minimum time available at the worst case. In this research, the simulation of the electromagnetic interference (EMI) in a Profibus network took place. The research also aimed to determine the magnitude of such interference in the Profibus system.

CHAPTER 3: METHODOLOGY

3.1 Introduction

Creswell [36] states that research methodology refers to a design according to which the researcher chooses data collection methods and analysis techniques to explore a specific research problem. Various methods, being either qualitative, quantitative or mixed (also referred to as hybrid), can be utilised, based on the type of research being conducted.

In this chapter, various methods that follow the quantitative research methodology were used to collect all the data that was needed to conclude the research. In essence, the methodologies carried out were those of design science research (DSR), which involved identifying the problem area, conducting the literature survey of the knowledge base, carrying out experiments, and performing the required simulation for the research.

Following the outcome of Chapter 1, and with the problem area defined, the research was conducted in line with the problem statement in mind, the research questions and the research objectives. As mentioned previously, the problem area lay within the pelletizing and sintering plant (PSP) at Samancor in the Limpopo region, where the industrial automation network was unstable and causing production loss. The main cause of the problem needed to be investigated, since many believed that the network was unstable due to the electromagnetic interference (EMI) that is believed to be induced on the industrial Profibus network whenever the network cable runs next to high voltage electrical cables.

The outcome of these research methods has answered the research questions that were posed in Chapter 1. The questions that needed to be answered were the following, as extracted from Chapter 1:

- What are the causes of network failure on the Samancor Profibus network?
- Are there any interferences that might be introduced into the Profibus network?
- If there is such interferences, to what degree is it interference?
- What is the performance of the network when another network cable is used on the PLC being used?

- How does the signal strength/voltage of the network compare to other stand-alone networks?

3.2 Research Design

Quantitative research design emphasises objectively on measurements and describing phenomena [32]. This research method involves many numbers, statistical data, structures and control. For this research, experiments were carried out on a PLC rig where a small Profibus network was built and configured for testing purposes. Two conditions or parameters were taken into consideration while testing the network for comparative purposes – i.e. (i) where the network was tested without faults or interference, and (ii) where there was induced interference.

The results or parameters that were extracted from the healthy network were used as the benchmark for the research. Moreover, references were made based on the attained values. Noise interferences were simulated onto the network using the welding machine, and thereafter an audit was carried out in the problem area which was in the live plant. This audit was done to evaluate the nature and degree of the problem in the plant’s Profibus network system as it was installed at the pelletizing and sintering plant (PSP) at Samancor Tubatse Ferrochrome during the time of the research. The outcome of the four research methods gave a factual indication that answered the question of whether the network was unstable due to noise interference or not. The research method conducted was quantitative, and was based on DSR. To carry out the objectives as tabulated in Chapter 1 of this study, an audit, simulation and experimental methods were carried out.

3.3 Setting and sample

'Research setting' refers to the place or the organisation where data are collected. This research was conducted at the Samancor Ferrochrome plant at the Tubatse region in Limpopo. The name of the department where the research was conducted is called the Pelletizing and Sintering Plant (PSP).

This section of the plant was sampled to carry out the research, because of the degree to which Profibus network failures were taking place and creating a high production downtime.

For operational reasons and business needs, there was also a need to build a stand-alone Profibus network system comprising Profibus equipment where experiments were done to avoid upsetting the plant when it was under operation. In essence, all the experiments were done offline, but verified on the live plant so as to check consistency.

There were three sampling techniques used, as follows:

i. Exploratory sampling: Exploratory sampling techniques automatically came into existence by virtue of examining the network during the network audits.
ii. Experimental sampling: Technical measurements were done and recorded according to set Profibus standards.
iii. Simulation: Tests were done to check the behaviour of the system under known configurations.

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3.4 Data collection

Polit and Hungler [33] define data as information obtained during the course of a research or study. In this study, experiments, simulations and plant network audits were used to obtain data relevant to the study's objectives and research questions. Engineering standards were reviewed, studies were conducted and courses were attended, in order for the research to be carried out. A network audit checklist was developed by the researcher to form a guideline as to which parameters and installation standards to consider while auditing the Profibus network. This checklist was done with reference to the Profibus installation standards as outlined by the Profibus Competence Centre South Africa (PCC) and distributed by the IDX Academy.

3.4.1 Reliability of the research instrument

The reliability of a research instrument "is the degree of consistency with which the instrument measures the attribute it is supposed to be measuring. Reliability can be equated with the stability, consistency or dependability of a measuring instrument" [34]. For this research, network equipment was purchased and used, to ensure that the information gathered would be accurate and reliable such that if other researchers were to repeat the research, the same results will be obtained.

Since this research was about Profibus network performance, Profitrace software and Profibus network tools were purchased with the corresponding licence, to enable the researcher to run tests and diagnose the Profibus network at any given moment. During this research, the Profitrace diagnostics tool was able to be plugged at any area within the Profibus network, as long as there was a piggyback plug to plug the tool [35]. The instrument was tested, and was declared reliable to give consistent results prior to the experiments being conducted.

3.5 Permission to conduct study

Permission to conduct the study was obtained and given in writing by Samancor Ferrochrome. All equipment used for conducting experiments constituted the property of Samancor Ferrochrome, and permission was given for their use, in order for the research to be conducted (see Appendix B).

3.5.1 Experimental configuration and setup of the Profibus network

In this setup, a small Profibus network was built on a PLC rig. The network consisted of three network nodes or devices (i.e. PLC, EM-station and the simocode). The PLC was the master and the EM-station and the simocode were the slaves. The Profibus cables were connected to form a daisy chain network topology configuration, and it ran from the CP-card of the PLC to the EM-station and ended at the simocode where it was terminated. The hardware configuration was configured by using the Siemens PLC software called the Simatic PCS7 V8.0 software. A virtual machine called the VMware workstation was used to run the PCS7 software. With the Simatic PCS7 software opened and running inside the VMware workstation software the following was conducted:

- A new project was created and named according to the research. In this case, the project was named “PAT_Network_Optimisation”.
- Inside the new project, the simatic 400 station was inserted.
- The hardware was configured with all the PLC cards added according to their serial numbers:

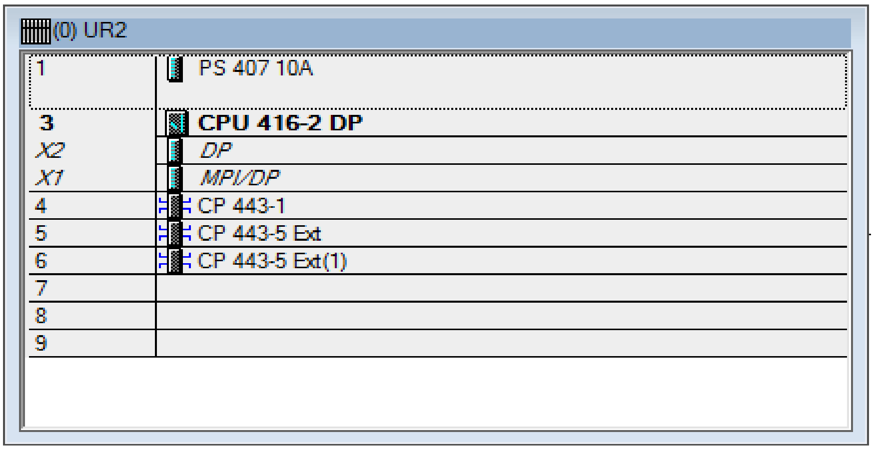


Figure 3.1: PLC Cards Hardware configuration slots (Tubatse plant, 2017)

As can be seen, slot 0 was the PLC rack where all the cards were inserted. The rack is referred to as UR2. In slot 1, a power supply with a part number of PS 407 10A was configured. In slot 2, CPU 416-2 DP was inserted and it took slot 3 as well. In slot 4, 5, and 6 three CP cards CP 443-1, CP 443-5 Ext and CP 443-5 Ext (1) were added, respectively. The properties of the CP cards as they were being added to the hardware were selected to status “networked” to enable a physical network to be connected or configured per card when needed.

In this case, CP 443-1 was used for communication, and the programing device was the laptop. CP 443-5 Ext was used for communication to the small network where testing and simulation was carried out. Figure 3.2 shows the complete hardware configuration of the PLC station:

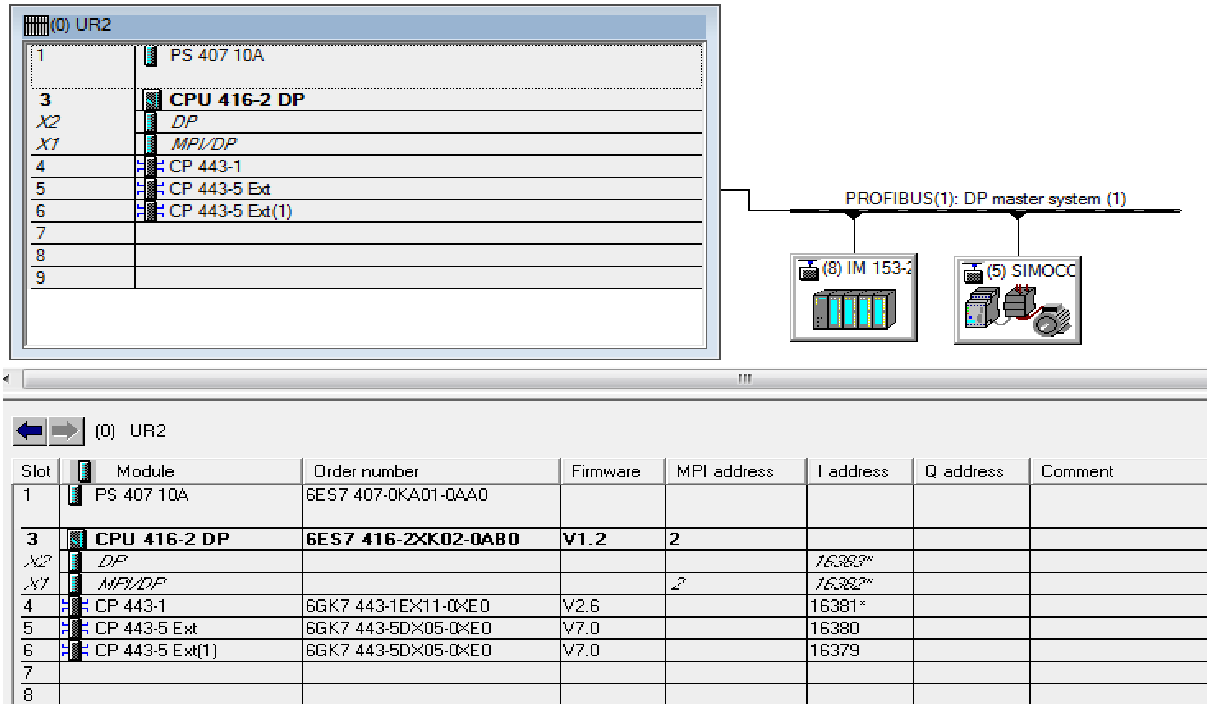


Figure 3.2: PLC hardware configuration (Tubatse plant, 2017)

The hardware configuration in Figure 3.2 shows that the CPU was the master, and it was assigned to node address 2. Still on Figure 3.2, it can be seen that the IM module (i.e. referred to as the ET-station module) was the slave, and its node address was assigned to node 8. The simocode was also the slave, and was assigned node address no.5. Still looking at the left pane of Figure 3.2, the CP card (i.e. CP 443-5 Ext) was configured for communication with the test network. Its properties were given a DP Master number system, and the EM-station and the simocode were also added, as shown in Figure 3.2.

Node address 8 on the right pane of Figure 3.2 was the EM-Station (Extension Module) and all its field I/Os were wired to it. The modules used were the digital input module, the digital output module, the analogue input module, and the analogue output module. Node address 5 was the simocode that ran the motor in DOL (Direct Online) configuration. The type of simocode used was the simatic pro-v series that was the latest version of simocodes that were still being manufactured by Siemens Automation during the time of the research. A hardware download was done to the PLC, but the PLC did not go to run mode because the simocode had not been configured yet.

The simocode had to be configured using the “SIMOCODE ES 2007 PREMIUM” software. The following steps were undertaken:

- The software was opened and the connection was established between the programing PC and the simocode unit.
- The Profibus parameter tab on the software was selected, and the station address was selected to node 5 to correspond with the hardware configuration of the simocode in the PCS7 PLC (see Figure 3.3):

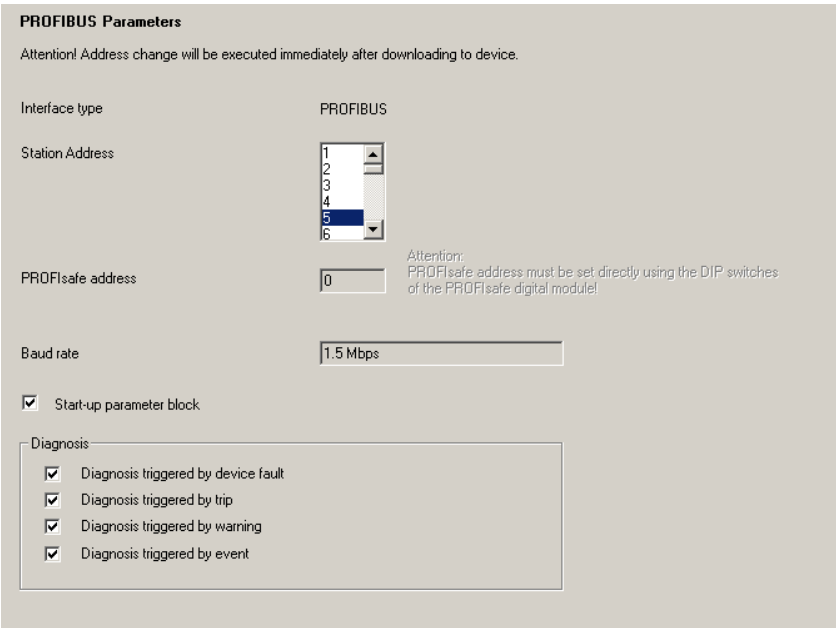


Figure 3.3: Simocode address setup for Profibus communication (Tubatse plant, 2017)

➢ As can be seen in Figure 3.3, the baud rate (i.e. network speed) was 1.5Mbps. These parameters must always correspond to the speed of the PLC.

When the PLC was started, it immediately went into run mode because communication was established, and the CPU could communicate to all the network nodes. See the status LEDs on all the PLC cards in Figure 3.4:

Figure 3.4: PLC status LEDs communication established (Tubatse plant, 2017)

The Profibus network was formed by wiring the three network nodes in a daisy chain network topology configuration, starting from the communication processor card which was the master. The network cables were daisy chained as follows:

i. Started from the CP card,
ii. To the ET-station,
iii. To the simocode unit and terminated at the simocode plug.

The network was terminated on both ends of the loop. See Figure 3.5 for clarification:

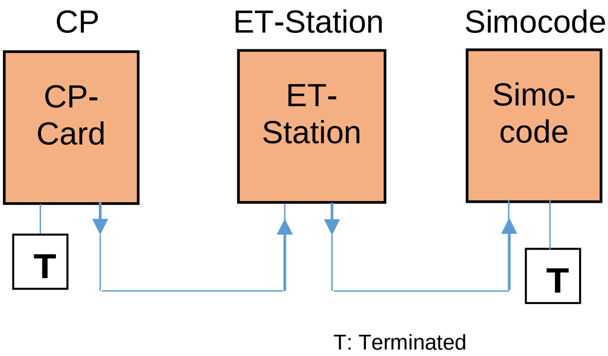


Figure 3.5: Block diagram of Profibus network in daisy chain configuration (Tubatse plant, 2017)

The hardware configuration was done using the simatic PCS7 software where the actual field hardware was matched with the PLC hardware configuration. All the hardware equipment values were entered manually into the simatic PCS7 software, and then downloaded. The software configuration of the network was done in a stepwise manner. As soon as the simatic hardware was compiled and downloaded, the communication auto-generated the values. This was confirmed by checking if every node matched the arrangement of the actual network. Figure 3.6 shows the auto-generated net-pro configuration of the network devices:

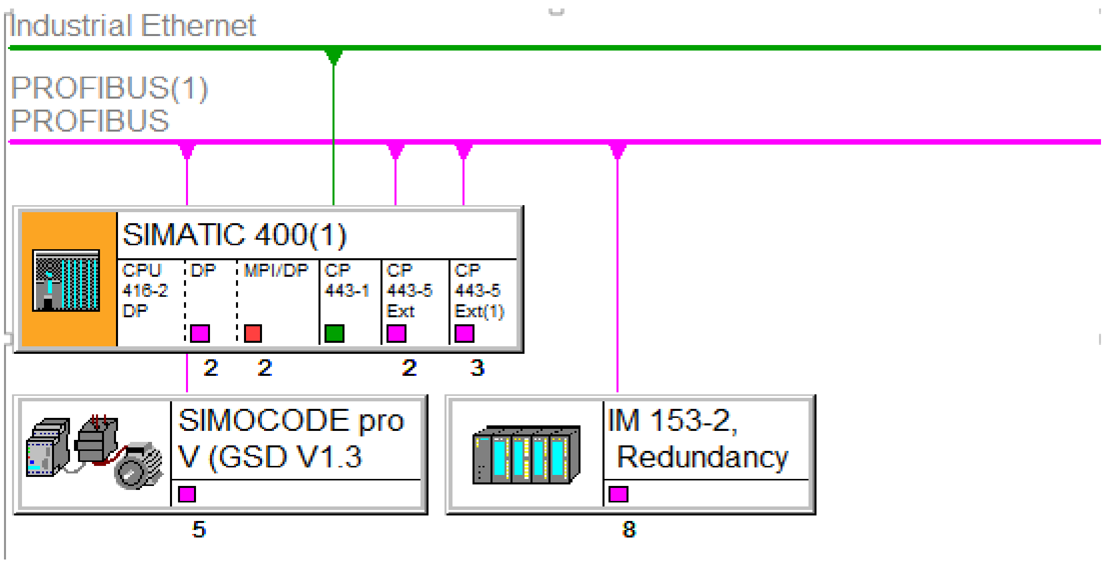


Figure 3.6: Auto-generated net-pro configuration of the network devices (Tubatse plant, 2017)

Now that communication was established and all the errors were cleared from the network devices, and with the PLC on run mode, a Profitrace software was used to check the condition of the Profibus network. This section of the dissertation discusses the conditions of the network, with special focus on the network condition, live list, and scope wave per node. The network condition was initiated and checked from the Profitrace ultra-core software, as soon as communication between the programming device and the network was established. The programming device gets connected anywhere within the Profibus network as long as there exists a connection point that is referred to as the piggyback. In this research, a laptop that was loaded with a Profitrace ultra-core software was used to check the condition of the network. Figure 3.7 shows the condition of the network:

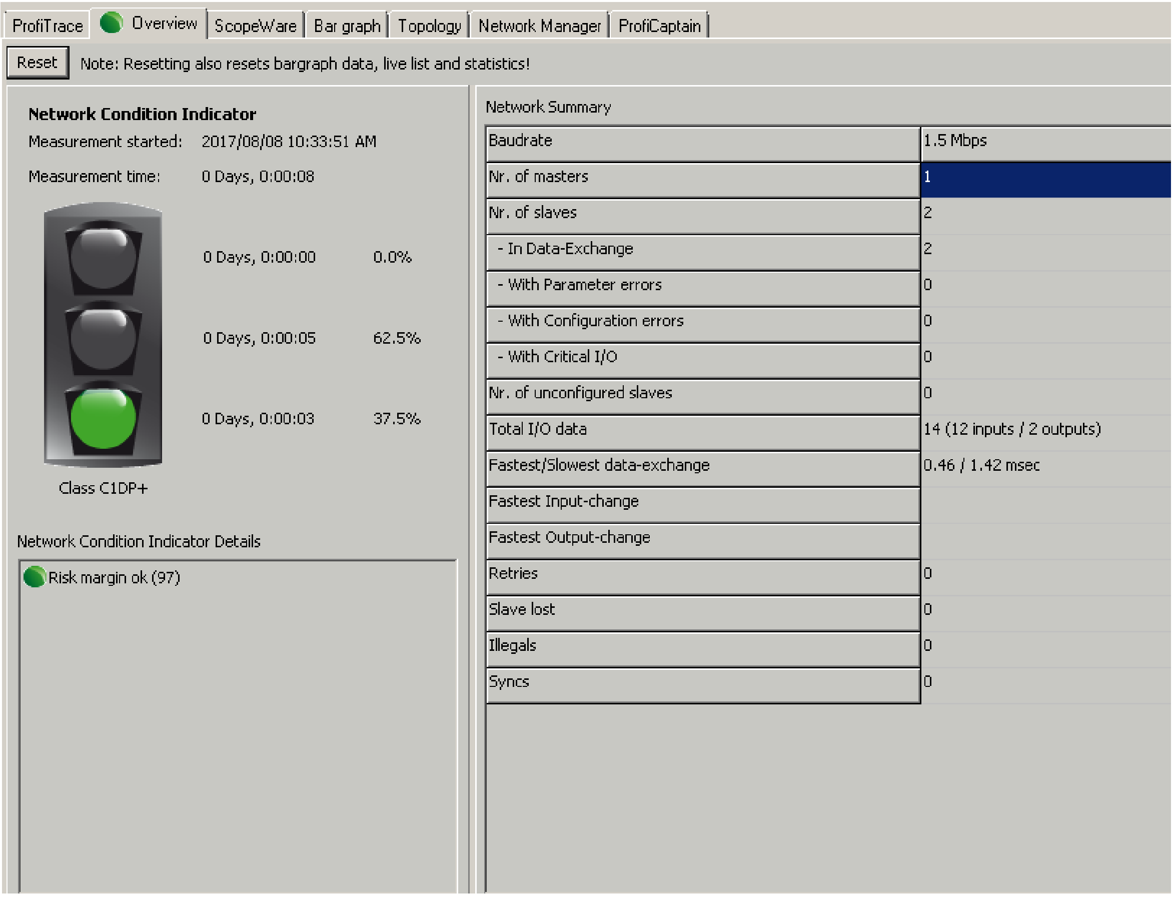


Figure 3.7: Network condition of small network on test (Tubatse plant, 2017)

In Figure 3.7, the green light indicates that the network was healthy (i.e. green, and had a risk margin of 97) when the baud rate of communication speed was 1.5Mbs. The network live list from the report indicated the numbers of network devices and the condition of the devices that were in data exchange.

The results were similar to those shown in Figure 3.8, but the colour of the device in the background showed the exact state of each device separately. Figure 3.8 shows the device condition with the legend of the background colours:

8 Live list

	0	1	2	3	4	5	6	7	8	9
0	0	1	2	3	4	5	6	7	8	9
10	10	11	12	13	14	15	16	17	18	19
20	20	21	22	23	24	25	26	27	28	29
30	30	31	32	33	34	35	36	37	38	39
40	40	41	42	43	44	45	46	47	48	49
50	50	51	52	53	54	55	56	57	58	59
60	60	61	62	63	64	65	66	67	68	69
70	70	71	72	73	74	75	76	77	78	79
80	80	81	82	83	84	85	86	87	88	89
90	90	91	92	93	94	95	96	97	98	99
100	100	101	102	103	104	105	106	107	108	109
110	110	111	112	113	114	115	116	117	118	119
120	120	121	122	123	124	125	126			

Legend:

	No activity	1	No activity
	Device is in data exchange	2	Master station
	Device is lost	3	Slave station
	Device has a parameter error		

Figure 3.8: Live list (Tubatse plant, 2017)

In Figure 3.8 it can be seen that the master was assigned a node address number 2 with a red colour. The slaves had a blue colour with the background colour of the devices that were in data exchange in green. Devices that were not configured were white in colour, which indicated that there was no activity taking place. The background colour will show yellow, red or pink when the device is lost, or if it has a parameter error, or if it has a configuration error, respectively.

From the Profitrace ultra-core software, a network topology was also displayed, as is shown in Figure 3.9. Figure 3.10, below, also shows the voltage strength of the network device on a Profitrace report.

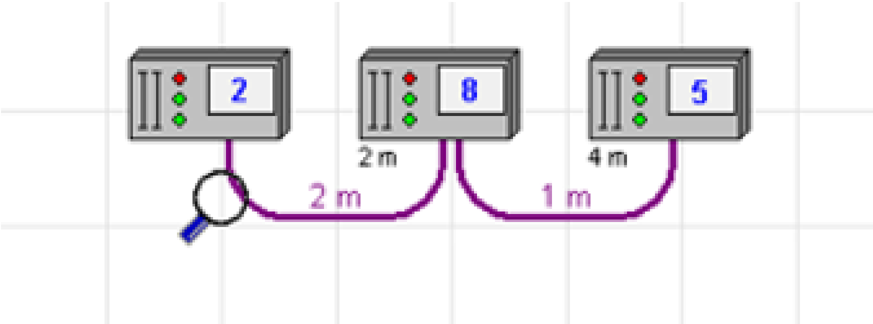


Figure 3.9: Network topology (Tubatse plant, 2017)

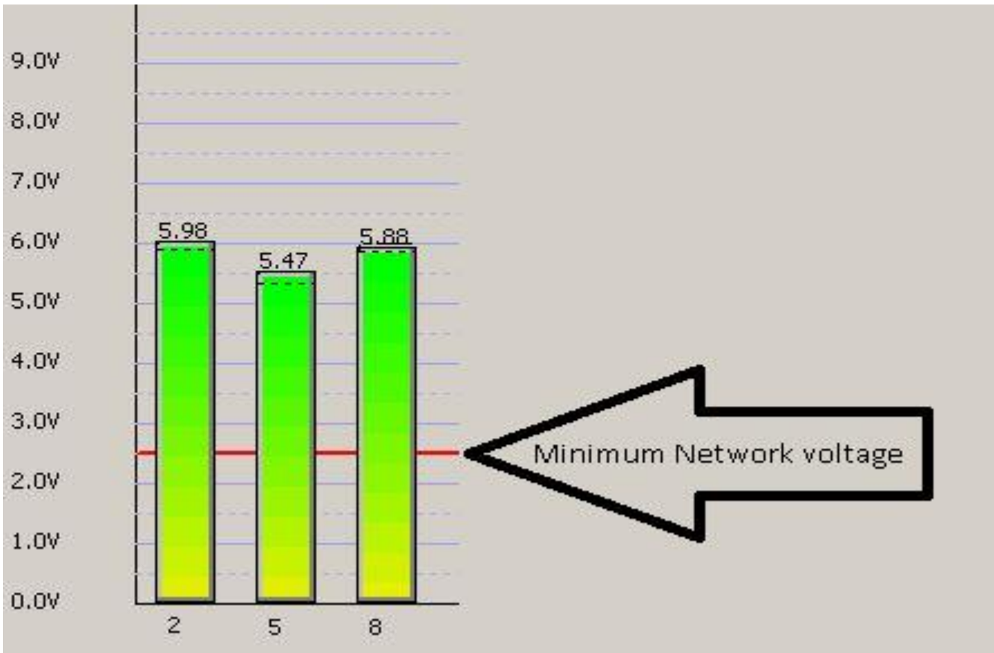


Figure 3.10: Voltage strength on the 3 network nodes (Tubatse plant, 2017)

From literature, the voltage should not be less than 2.5v and not more than 7.2v Also, Figure 3.10 shows that network nodes were running optimally. The scope-wave for node no.2, no.5 and no.8 when the network was not put under any form of interference and when the network was simulated, were taken, respectively. The scope-wave of how the network behaved all appear in the results section of chapter 4.

3.2.1. Research scenario 1: An audit of the real time plant network

In this setup, an audit of the entire Profibus network at the pelletizing and sintering plant (PSP) was carried out. The audit involved two types of inspections (i.e. the software audit and the installation standard audit). A checklist of parameters that were audited appears in Appendix C of the reference section.

3.5.2 Experiment 2: Running tests to create a benchmark on a clean, healthy network

Experiment 3 was conducted to create a benchmark where the parameters that surfaced from Experiment 1 served as a guideline or reference. This experiment was conducted on the small Profibus network that was built on a PLC rig for benchmarking. This network was not exposed to any external interference when the experiment was conducted. Figure 3.11 shows the block diagram of how a Profitrace PC was connected to the Profibus network. The Profitrace tool or PC can be connected anywhere on the Profibus, provided that there is a piggy-back plug installed.

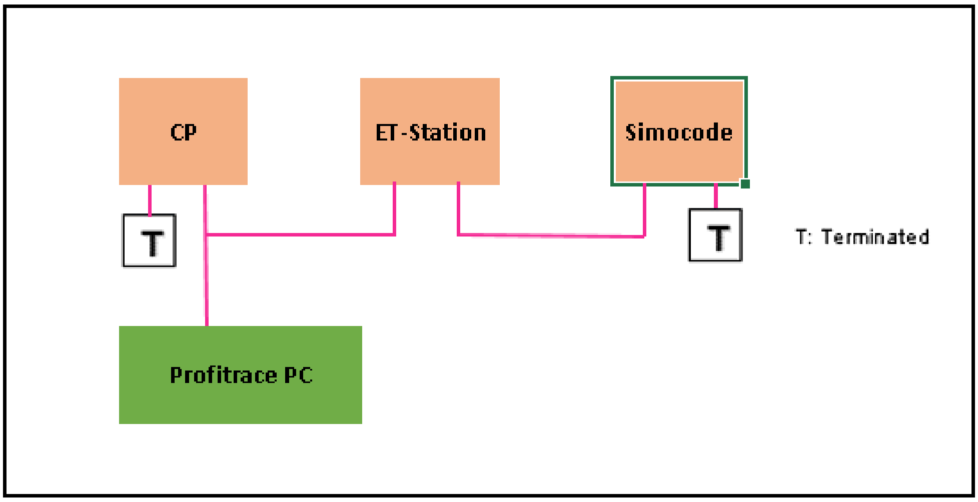


Figure 3.11: Network arrangement with Profitrace connected

3.5.3 Experiment 3: Injecting interference into the shielded Profibus network

In this setup, an electrical magnetic interference (EMI) or noise was induced into the small Profibus network using a 220V welding machine. The welding machine cables were wrapped around the Profibus network cable prior to welding and a Profitrace report was generated while welding was taking place, to determine if there were any visible changes to the network condition.

The metal plate was attached to the ground potential to allow current to flow from the welding machine to the ground. Focus was given particularly to the amount of change that took place on the scope-wave of the Profibus device. Figure 3.12 shows such an arrangement. The respective image of how the network was connected is shown in Figure 3.13, below.

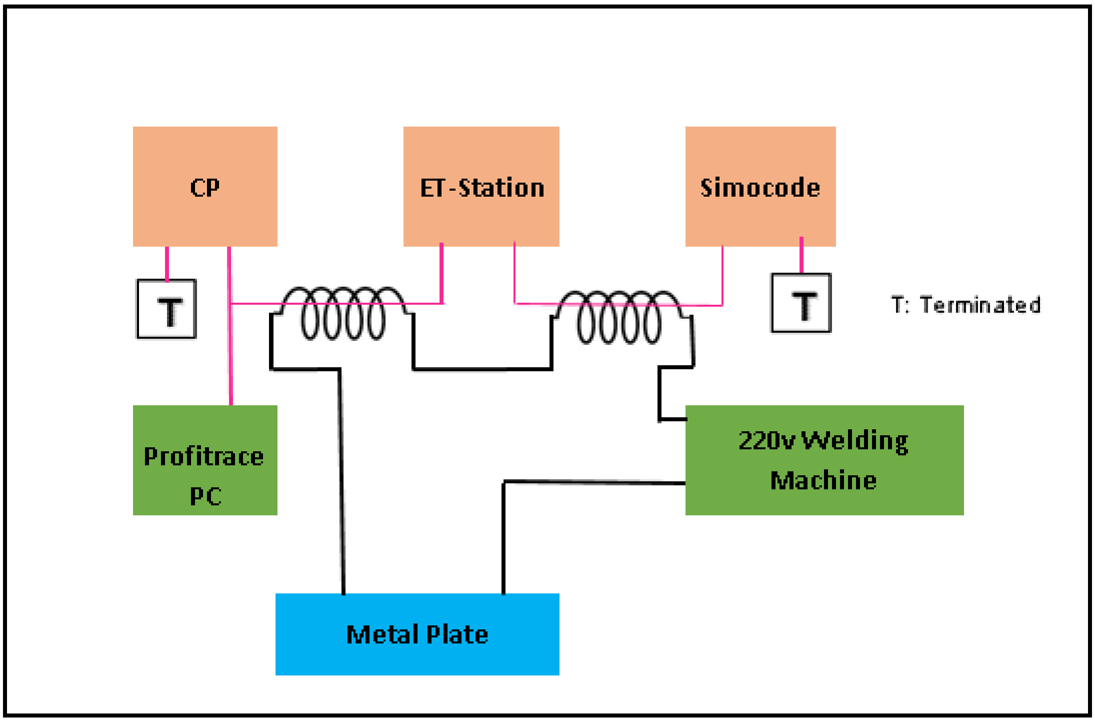


Figure 3.12: Block diagram of the network: Profitrace and 220V welding connected

Figure 3.13: Injection of EMI with a 220V welding machine (Tubatse plant, 2017)

The welding current that was transferred through the welding rods was adjustable by using a potentiometer knob that was situated on the front side of the welding machine. In these experiments the response of the scope-wave was tested at different welding current flow to the welding rod. Table 3.1 highlights the settings of how much current was Injected or simulated while welding at different set intervals. Note: Only the 220V welding machine was used, but the current was varied.

Table 3.1: Injected current intervals at 220V (parameters)

Simulated interval number	Current Magnitude (A)	Voltage Level (V)
1	0	220
2	40	220
3	80	220
4	110	220
5	140	220
6	170	220
7	220	220

3.5.4 Experiment 4: Injecting EMI on the unshielded Profibus network

In this experiment, the same setup as described above was carried out. Except that the shielding on the Profibus cable was removed from the earth potential or ground. This was done to see how the network would behave when the installation standard pertaining to grounding/shielding was not adhered to. Basically, both ends of the Profibus cable were removed from the earth potential such that grounding was ignored completely. Figure 3.14 shows how the network shielding was removed from the Profibus plug of the CP card on the main PLC rack:

Figure 3.14 : Unshielded Profibus network cable (Tubatse plant, 2017)

Welding cables were also wrapped around the unshielded Profibus cable, with welding commencing at different current adjustments. The results or findings of how the network behaved is as shown in the results section of Chapter 4.

3.5.5 Experiment 5: Substituting a Profibus cable with a shielded twin flex cable and injecting EMI

In this setup, the Profibus cable was removed and replaced by a normal shielded twin flex cable. This experiment was done to understand how a different cable would react to the same conditions as the Profibus cable would. This experiment was conducted to check if the Profibus cable was the best cable for the Profibus network or not. Figure 3.15 shows the setup where the shielded twin flex cable was used. Electromagnetic interference was also induced using a welding machine to understand the response of the network to a different cable. The results or findings of how the network behaved is shown in Chapter 4.

Figure 3.15: Shielded twin flex cable used on Profibus network (Tubatse plant, 2017)

Electromagnetic interference was also induced using a welding machine to understand the response of the network to a different cable. The results or findings of how the network behaved is also covered in the results section of Chapter 4.

3.6 Simulation configuration and setup of the Profibus network

The simulation experiment focused on the behaviour of the message signal that was transmitted throughout the Profibus system. Parameters that were being given focus were the change in the amplitude of the signal when it was exposed to different interference levels, the change in the shape of the signal, and the peak-to-peak voltage change of the signal. In essence, the distortion of the original signal was given more attention.

3.6.1 Experiment 1: Model based simulation of the plant network

For this experiment, a MATLAB software was used to simulate the live network of the PSP's Profibus system. The Profibus drawings of the plant were used to build the network. (Refer to Appendix A for the PSP Simulink network drawings that were used to build the plant network). Figure 3.16 shows the control system representation of the plant's Profibus network using Simulink software. The sub-systems were created and linked together to form the main system that represented the PSP's Profibus network (refer to figures 3.17 and 3.18).

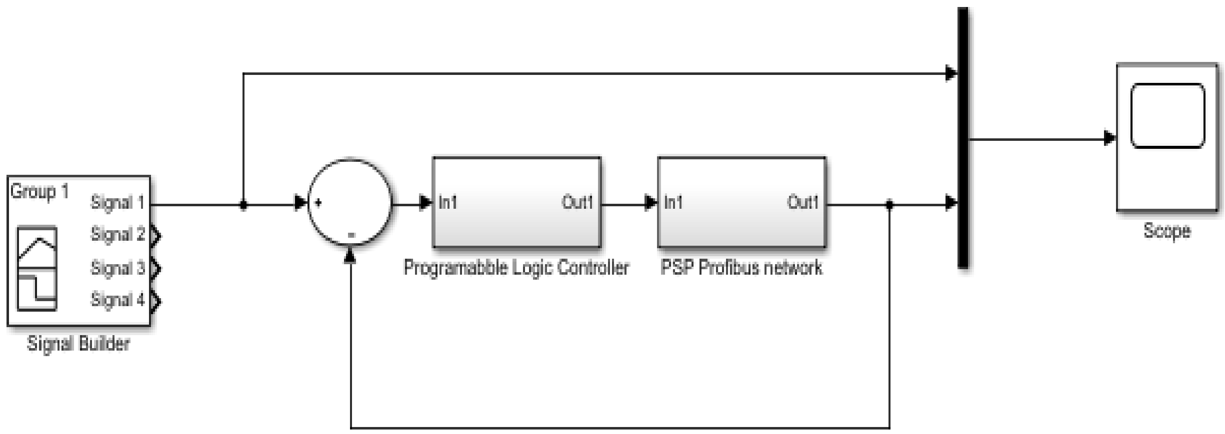


Figure 3.16: Simulation layout of the PSP Profibus network

The signal builder on Figure 3.16 represents the supervisory control and data acquisition (SCADA) system where the operator of the plant would input the required data to the respective client PC, and the instructions from the SCADA would travel through the network and be executed by the programmable logic controller (PLC) through the client/server communication stream.

In Figure 3.16, the PSP Profibus network appears as a single block, but in actual fact it comprises 22 network devices (refer to Appendix A on the reference page for the network drawing in daisy chain configuration). Simulink simplifies the appearances of the large network into a single block by grouping the different sub-systems into one system. Network nodes that made up this network consisted of one communication processor (CP), eleven EM-stations; four variable speed drives (VSD) and six conveyor belt weighing system integrators (i.e. Unipro-4 series). The PLC communicated with all the network devices through the CP card. The repeaters, network switches, network hubs and end-of-loop terminators did not form part of the network, as they were on other network segments that, for the purpose of this research, were not analysed.

This Profibus network consisted of both the closed loop and open loop systems which were controlled centrally by a programmable logic controller (PLC). Figures 3.17 and 3.18 show the closed loop and the open loop diagrams of the network nodes, respectively.

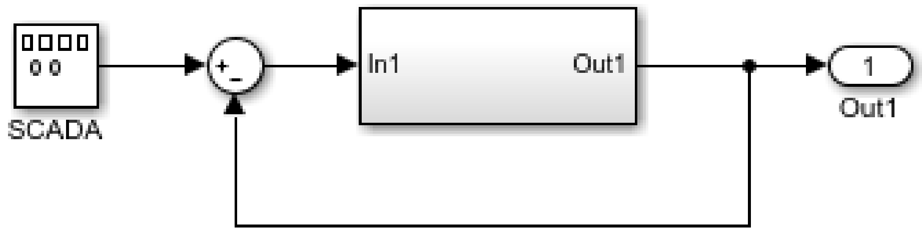


Figure 3.17: Closed loop control system

Figure 3.18: Open loop control system

The PLC, VSDs and the EM-stations follow the closed loop configuration system which uses a feedback loop mechanism to achieve the preferred set point. The Unipro-4 follows the open loop configuration system, and it does not need to monitor the output. The output is for display purposes. The network devices were therefore connected in a daisy chain network topology as shown in Figure 3.19, and were terminated at the end of the loop by the active terminator.

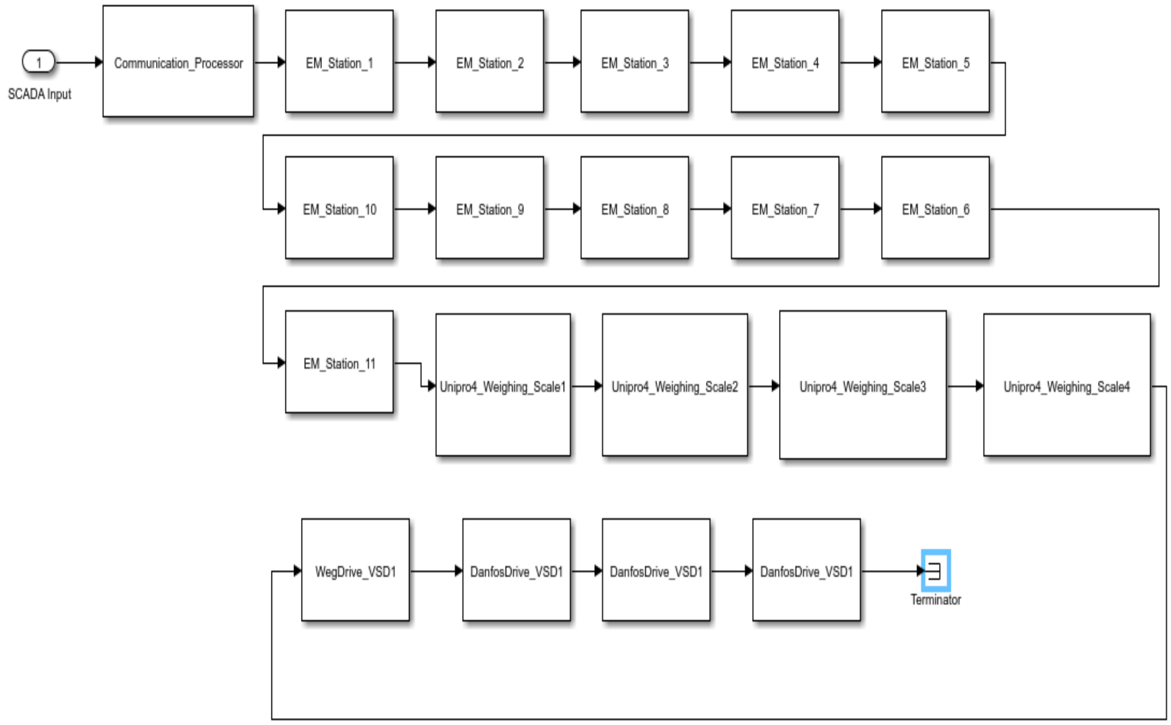


Figure 3.19: Simulation set up for PSP Profibus network

The idea of this experiment was to simulate the network with noise using the MATLAB software, and to observe the behaviour of the network, as opposed to when there was no interference simulated. The simulated noise represented the electromagnetic interference (EMI) that was believed to be the reason for the instability in the Samancor Profibus network at the PSP department. Noise interference was simulated onto the Simulink plant as shown in Figure 3.20. The results of the behaviour of the network are covered in Chapter 4 of this report.

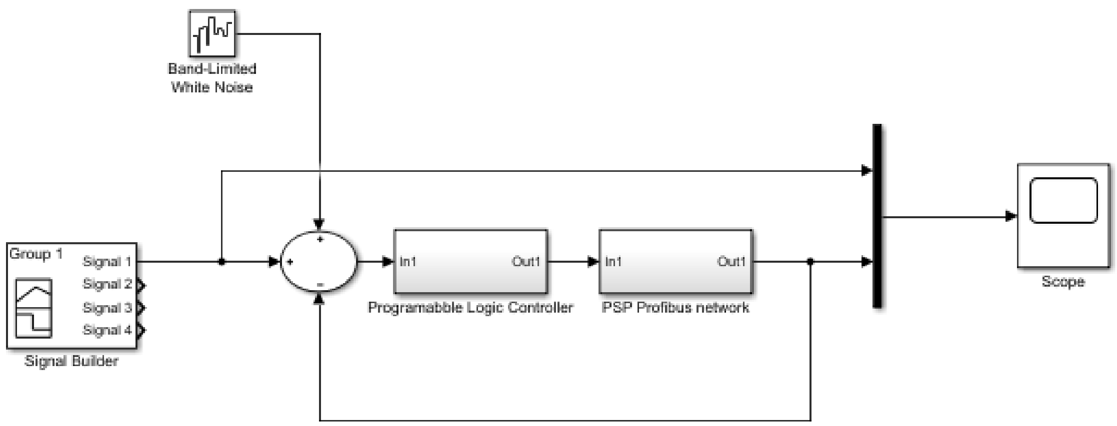


Figure 3.20: Simulation of EMI onto the PSP Profibus network using Simulink

Simulink has a built-in 'signal block' that can be configured to generate a signal which is sent to the plant network. For this experiment, four signals were configured with the signal generator and applied to the Profibus network, and the results on the output oscilloscope were observed. Figure 3.20 indicates the signal generator block and the four signals that were configured to be sent through the Simulink plant. The signal generator represents the signal that is equivalent to the signal that is sent by the operator of the plant using the SCADA system.

The signals were sent and observed individually without interference. They were then sent and observed when there was noise interference induced into the network. When individual signals were sent, the signal generator was configured to output signals on the respective ports. When all signals were sent at once, they also appeared on the output bus at the same time. The results of this experiment are discussed in the results section of Chapter 4.

Simulink also has a built-in 'band limited noise block' that can be configured to generate a signal which is sent to the plant network to interfere with the signals sent by the SCADA system, and the results can be observed from the output oscilloscope. For our experiment, the interference was incremented in a linear fashion from the noise power of zero to six, to see the degree of signal distortion.

The command signal that was sent onto the Profibus system had a destination address attached to it. The network nodes whose address was identical to the destination address on the command message were able to receive and execute the required instruction from the command.

3.7 Conclusion

This chapter discussed, in detail, the research methodology that was used to conduct the study. The quantitative research methodology was used to gather all the necessary data, so that the problem statement could be resolved. The type of methodology used to gather information was that of experimental, simulation and layered audit. The research design, data sampling and data collection instrument were discussed. Chapter 4 covers the data analysis and the findings from the methodology chapter.

CHAPTER 4: RESEARCH FINDINGS AND DISCUSSION OF RESULTS

4.1 Introduction

This chapter presents the results that came out from the experiments that were conducted in the preceding methodology chapter. Five experiments were conducted, with the intention to cover the research objectives and to answer the research questions as stated in Chapter 1 of this research. The research questions and objectives as extracted from Chapter 1 are tabulated in Table 4.1, as follows:

Table 4.1: Research questions and research objectives

Research Questions	Research Objectives
What are the causes of network failure on the Samancor Profibus network?	To evaluate the performance of the network using standard testing determine methods to see if there are any interferences that might be introduced into the Profibus network.
Are there any interferences that might be introduced into the Profibus network?	To compare different network cables that can be used on Profibus network PLC.
If there are such interferences, to what degree is it interference?	To measure whether the signal strength/voltage of the network is sufficient.
What is the performance of the network when another network cable is used on the PLC being used?	To test and simulate the network using parameters in objectives 1 and 2, and compare with the physical performance of the network.
How does the signal strength/voltage of the network compare to other stand-alone networks?	

4.2 Experimental results and analyses

4.2.1 The results of Scenario 1

This was a network audit experiment. Two types of network audits were conducted, and the results are tabulated in Table 4.2:

Table 4.2: Network audit checklist

NETWORK AUDIT			
Software Audit	**Number of defects found**	**Installation Standards Audit**	**Number of defects found**
Live list status	22	Minimum cable length of 1M between network devices.	2
Syncs	14	Maximum segment length of 1000M	0
Station lost	0	Earthing and/or shielding of the screen cable	4
Interference / Reflections	7	Bending of the profibus cable	2
Retries	0	Running of the profibus cable next to high voltage cables or power line or running the profibus cables in high voltage cable trays	6
Duplicated address	0	Air separation distance between Profibus cables and power lines	5
Voltage levels on bar graph	20	Redundant equipment	1
		Illegal installation	3
		Physical damage	0
		Drawings	2

4.2.1.1 The software audit results

Table 4.2 shows that there were 22 network devices that were configured in the Profibus network. Out of the 22 devices, 14 created syncs and 20 had voltage levels that were unstable; however, there were no stations that were lost, 0 retries and no duplicated addresses. Seven of the network devices showed reflections on the edges of their scope-wave.

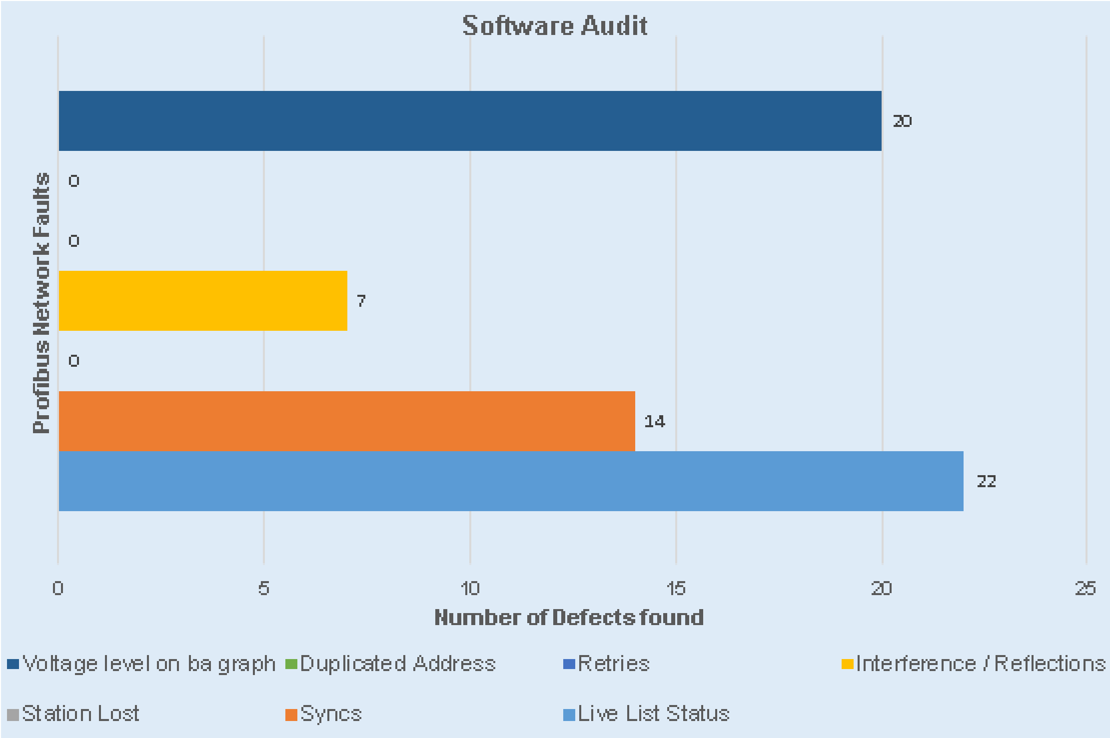


Figure 4.1: Network audit – Software

4.2.1.1 Analyses of the software audit results

The software audit of the network focused specifically on the integrity of the network with special focus on the following parameters as they appear in the literature review chapter. The Profitrace network was used to conduct the software audit. Network parameters that were given special focus when conducting the software audit, are the live list status, syncs, station lost, interference/reflections, retries, duplicated addresses and voltage levels on bar graph.

The results, as noted from the software audit report, indicated that that there were 22 nodes on the Profibus network which were specified as “live list”. The 22 devices were network nodes that were on data exchange. This indication is not a problem, but just an indication that the devices are available and healthy. Out of the 22 nodes, the Profitrace tool revealed that 14 nodes had syncs. That means that these devices were struggling to communicate with other devices. The bar chart also shows that there were seven (7) devices that had reflections. It can be concluded that the 14 devices that had syncs could not communicate properly due to interference in the Profibus network.

The network report was generated at the real time plant environment, using the Profitrace diagnostic software. This report was generated while the PSP plant was running at full capacity. The name of the network that was evaluated is called the 'auxiliary network', and tests were done on the DP1 segment. Figure 4.2 and 4.3 show the network devices that were present and their voltage levels, respectively:

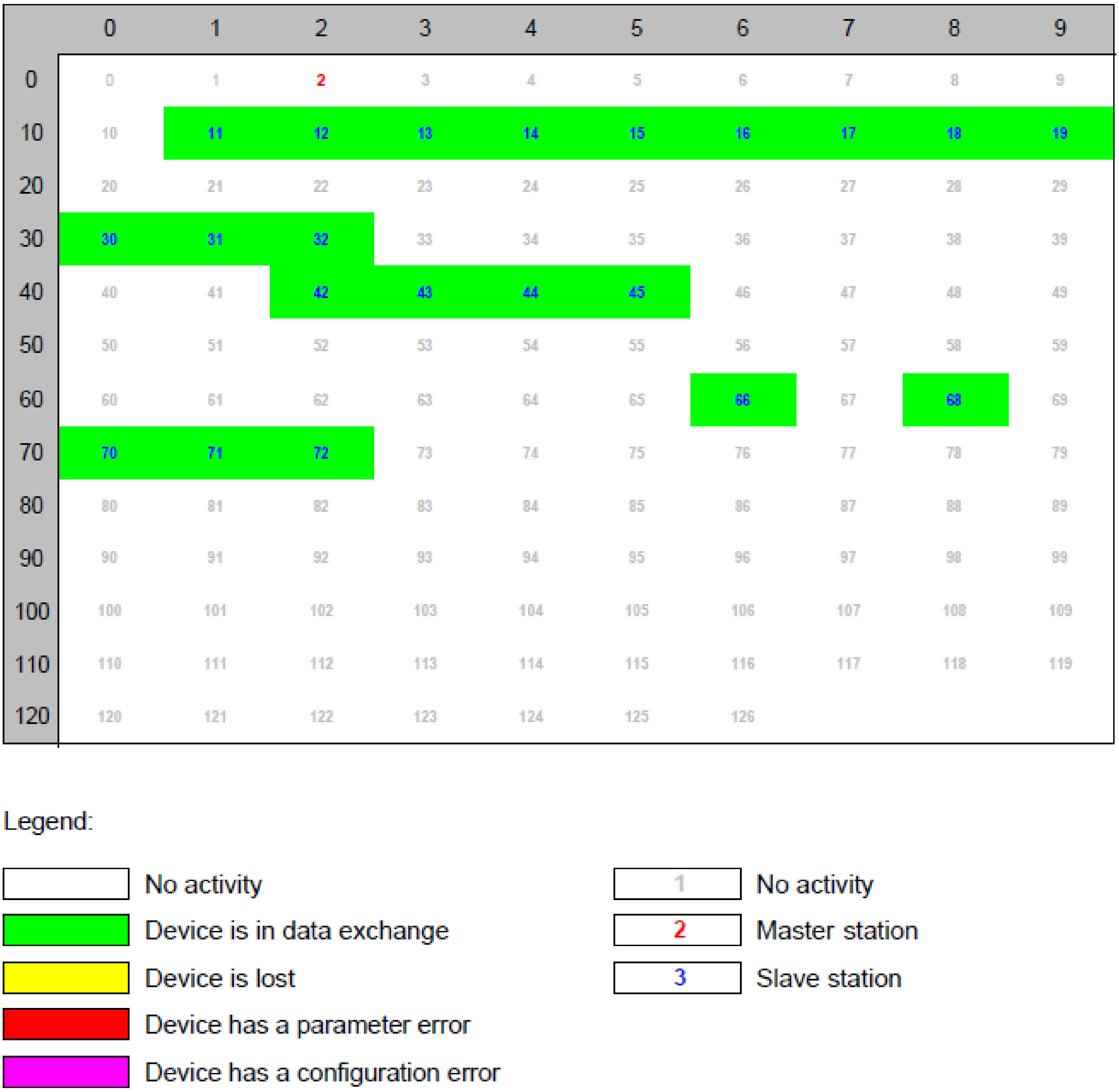


Figure 4.2: Live list of the PSP auxiliary network (Tubatse plant, 2017)

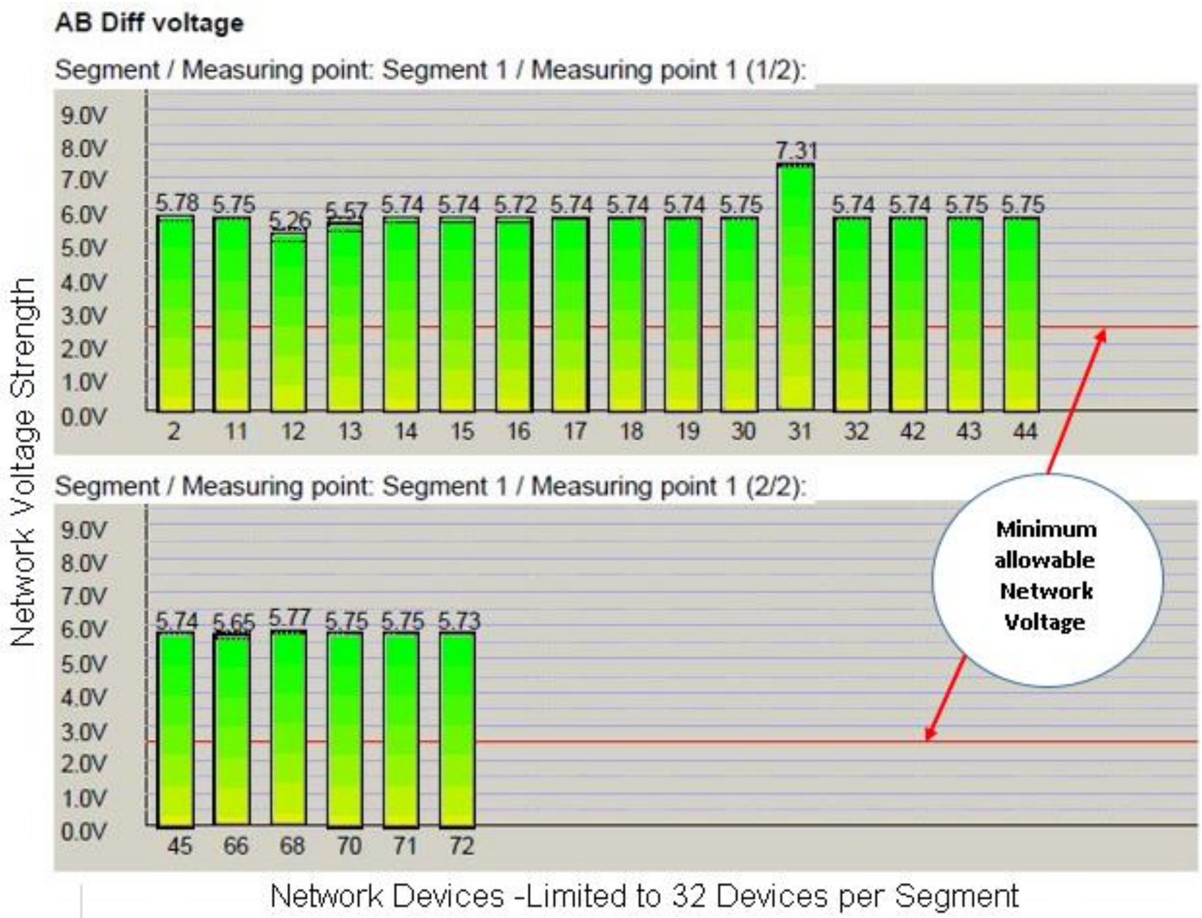


Figure 4.3: Voltage levels of the PSP auxiliary network devices

The green background behind the network nodes in Figure 4.2 of the “live list” shows the network nodes that were available and communicating properly when the report was generated. The 14 (fourteen) network devices that showed network syncs are shown with the red cross inside square brackets **[X]** on line 6.6 of the tested results in Figure 4.4. Network devices that showed syncs were 10,40,41,48,49,50,51,52,53,60,61,62,63 and 64.

6.1 Slaves that have been lost at least one time:	None	✓
6.2 Slaves that generated diagnostics while in data exchange:	None	✓
6.3 Devices that have caused illegal responses:	None	✓
6.4 Device found on reserved address 126:	None	✓
6.5 Slaves that caused retries:	None	✓
6.6 Slaves that caused syncs: *Some types of ABB DCS systems continuously send Sync messages. This does not influence the bus communication. These Syncs can be ignored.*	10, 40, 41, 48, 49, 50, 51, 52, 53, 60, 61, 62, 63, 64	✗
6.7 Parameters have been sent to the following slaves:	None	✓

Figure 4.4: Profitrace detailed network report

The report also shows reflections on the waveform of the oscilloscope. Figure 4.5 specifically showed a waveform of node address no.12 when the report was generated:

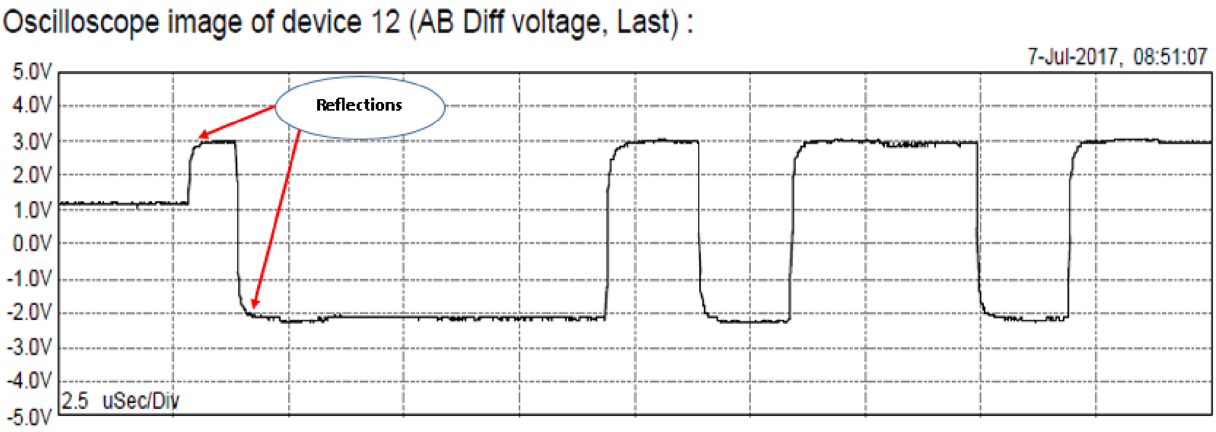


Figure 4.5: Oscilloscope wave showing distorted edges

4.2.1.2 The installation standard audit results

The installation standard audit was conducted, and it was discovered that standards were not adhered to during the initial installation; also, due to time and lack of knowledge, several factors started influencing the Profibus installation standard even further. The following were observed: wear due to incorrect IP selection; new electrical installation was done next to existing Profibus network; earthing/shielding problems; network cables less than 1M between network nodes/devices; redundant equipment not removed from the Profibus network; drawing not updated; and, difficulty in tracing the network.

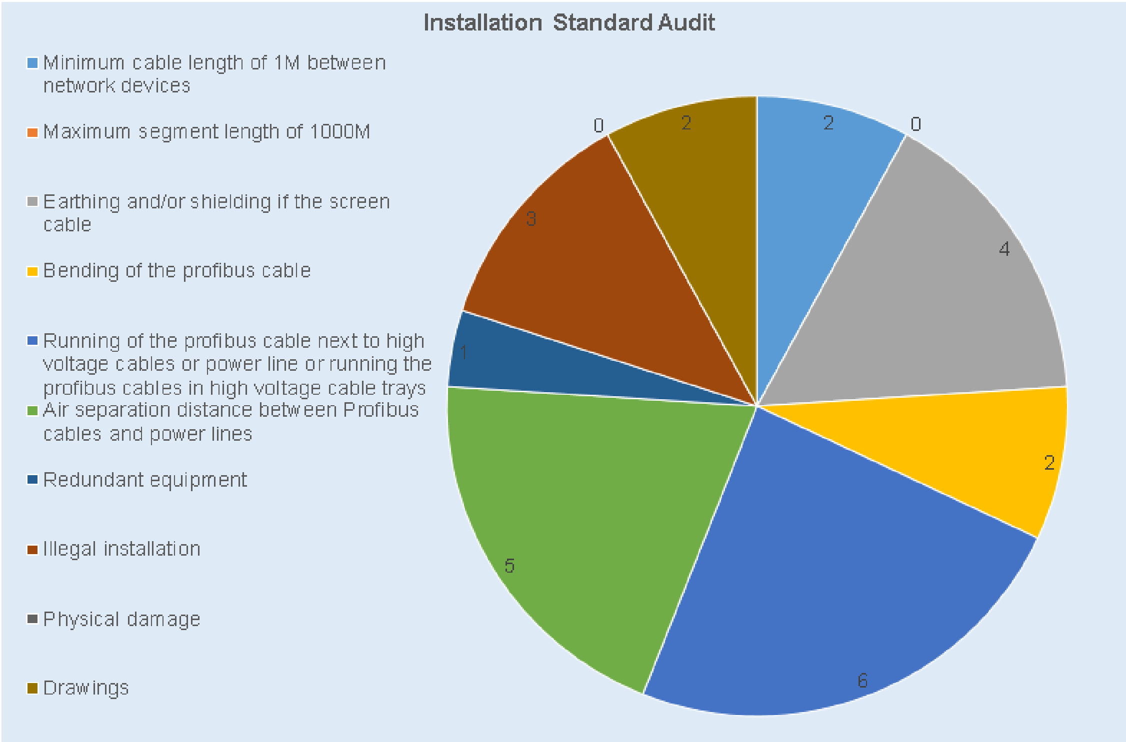


Figure 4.6: Network audit results for Samancor ferrochrome

The installation standard audit also focused on the inspection of the physical installation of the network, in order to check compliance with the Profibus installation standards. Standards that were audited included, but were not limited to, the minimum cable length of 1M between network devices, the maximum segment length of 1000M, the earthing and/or shielding of the screen cable, the bending of the Profibus cable, running of the Profibus cable next to high voltage cables or power line, or running the Profibus cables in high voltage cable trays, air separation distance between Profibus cables and power lines, redundant equipment, illegal installation, physical damage and the drawings.

4.2.1.1 Analyses of the installation standard audit results

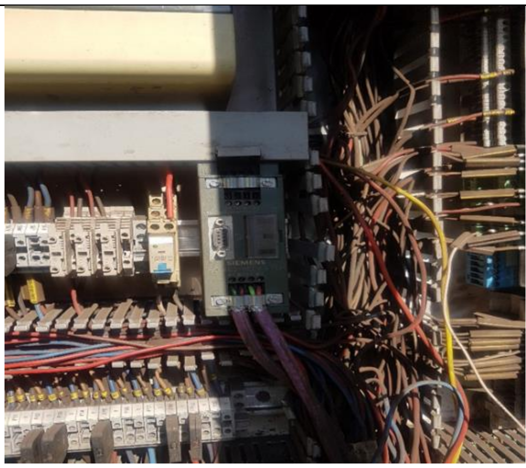
Appendix A shows the drawings of the PSP auxiliary network where the installation standard audit was carried out. The audit was conducted with specific focus on the installation standard adherence, and also to see if the network drawings are in correlation to the field layout of the network. During the inspection audit, it was discovered that standards were not adhered to during the initial installation, and also that due to time and lack of knowledge, many factors started influencing the Profibus installation standard even further.

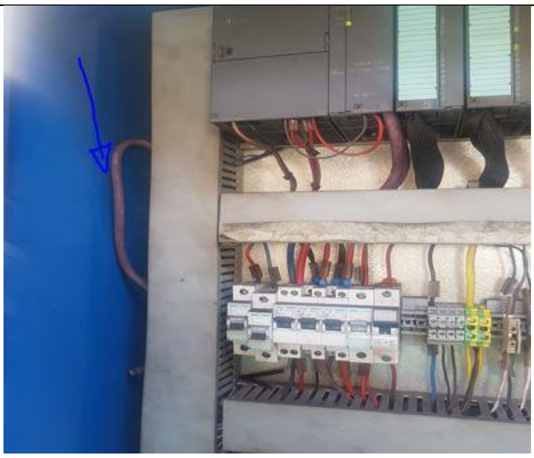
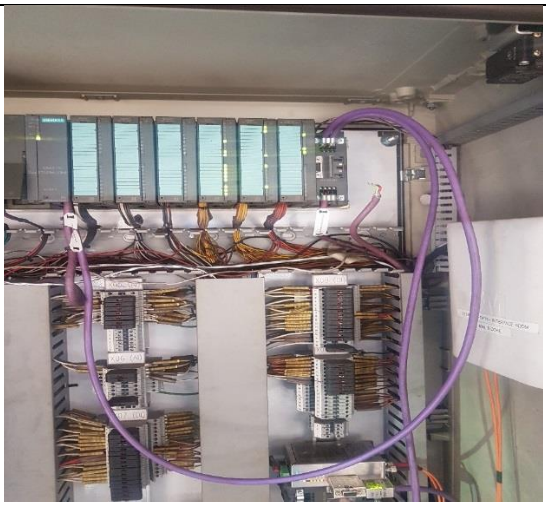
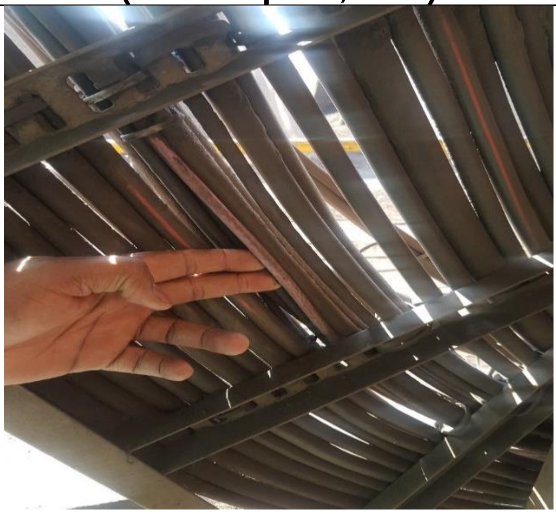
The following were observed:

i. New electrical installation was done next to an existing Profibus network.
ii. Air separation between the Profibus cable and high voltage cables was too minimal.
iii. Earthing/shielding problems.
iv. Network cables less than 1M here between network nodes/devices.
v. Redundant equipment not removed from the Profibus network.
vi. Drawing not updated, and difficulty in tracing the network.
vii. Wear due to incorrect IP selection.

The following figures in Table 4.3 show the substandard network installation that was observed during the network installation standard audit at the pelletizing and sintering plant at Samancor:

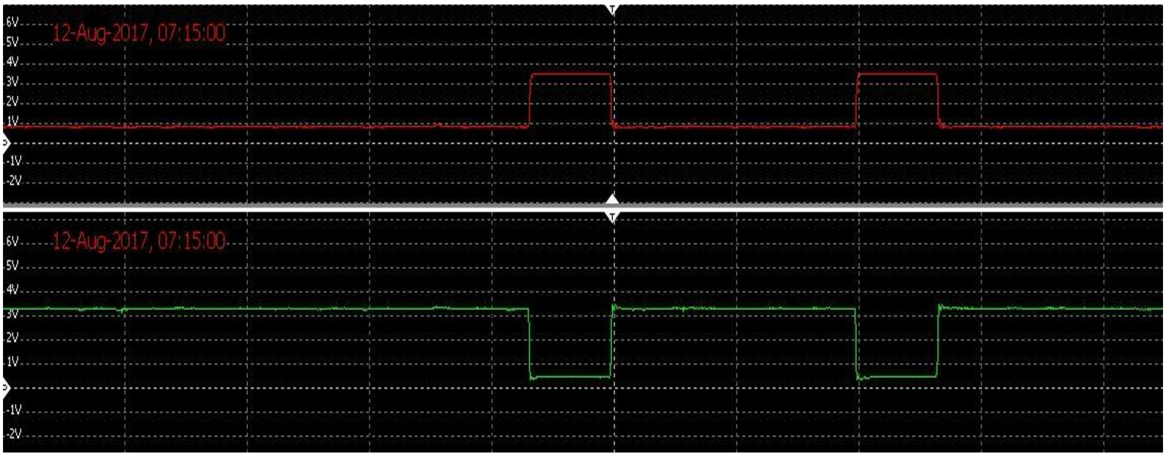
Table 4.3: Pictorial findings of the network audit

Network audit faults	**Pictorial view of observed faults**
Figure 4.7 shows a Profibus network repeater that was part of the network loop, but the device was not powered with the 24V supply power.	 **Figure 4.7: Redundant network device – not powered (Tubatse plant, 2017)**

The Profibus cable is shown in Figure 4.8 where the cable was bended so much that it made a 90-degree bend.	 **Figure 4.8: Bent Profibus cable (Tubatse plant, 2017)**
The ET-Station in Figure 4.9 shows a Profibus cable that was hanging in the air and not connected or terminated.	 **Figure 4.9: Unterminated network cable (Tubatse plant, 2017)**
Figure 4.10 shows a Profibus network cable running between the electrical cables inside the same cable rack.	 **Figure 4.10: Network cable between high voltage cables (Tubatse plant, 2017)**

4.2.2 Experiment 2 results

This experiment was conducted purely to see the behaviour of the network when there was no interference injected into the network. The network oscilloscope conditions were recorded and documented as shown in Figures 4.11 and Figure 4.12:



Note: X-axis represents time in 2.5µSec/div, and Y-axis represents 1V/div (volts).

Figure 4.11: Profibus wires A&B data scope wave (Tubatse plant, 2017)

Note: X-axis represents time in 2.5µSec/div, and Y-axis represents 1V/div (volts).

Figure 4.12: Difference scope wave between wires A&B (Tubatse plant, 2017)

Figure 4.11 and Figure 4.12 show the shape of the scope waves of the green and red wires inside the Profibus cable and the difference waveform report, respectively. The Y-axis represents the network voltage signal, and the X-axis represents the number of bits passing through per second.

4.2.3 Experiment 2 results analyses

All the network devices generated smooth square data waveforms. There was no distortion on the waveforms and therefore the data was not distorted. The peak-to-peak voltage observed from the A&B difference waveforms showed approximately V (p-p) ≥ 5v. The network master and all slaves were healthy. There were no illegal responses. None of the slaves caused syncs. None of the slaves caused retries. None of the slaves generated diagnostics while in data exchange. There were no lost station or slaves.

This analysis was taken from the report generated by the Profitrace software tool, and also from the behaviour of the network as observed while monitoring the network at real time with the Profitrace tool. This experiment became a benchmark later on when conducting experiments 3, 4 and 5. The aim was to answer research question no.2 and no.4, as stated in Table 4.1. As can be seen, only the three network nodes that were configured on the small network appear and are detected by the Profitrace tool, as healthy network devices.

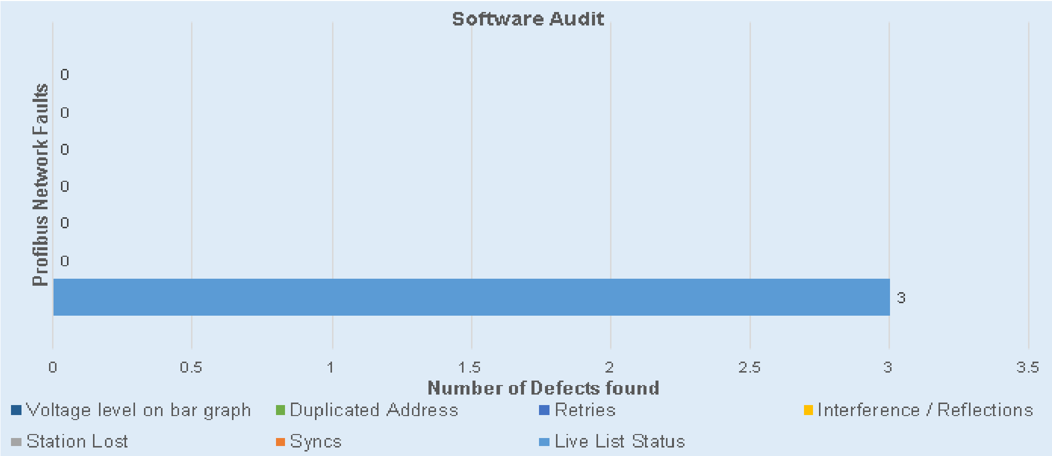
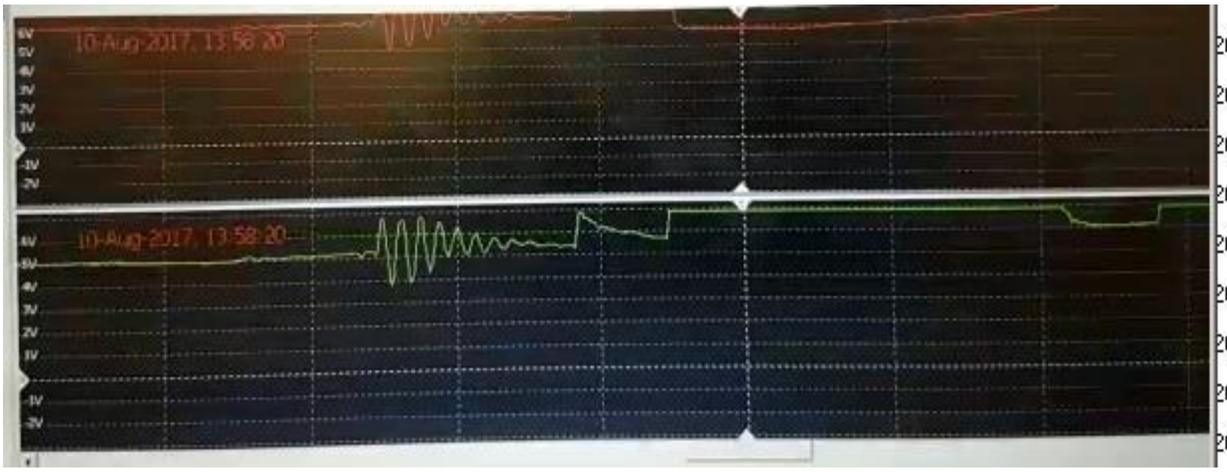


Figure 4.13: Network audit results for small test network without interference

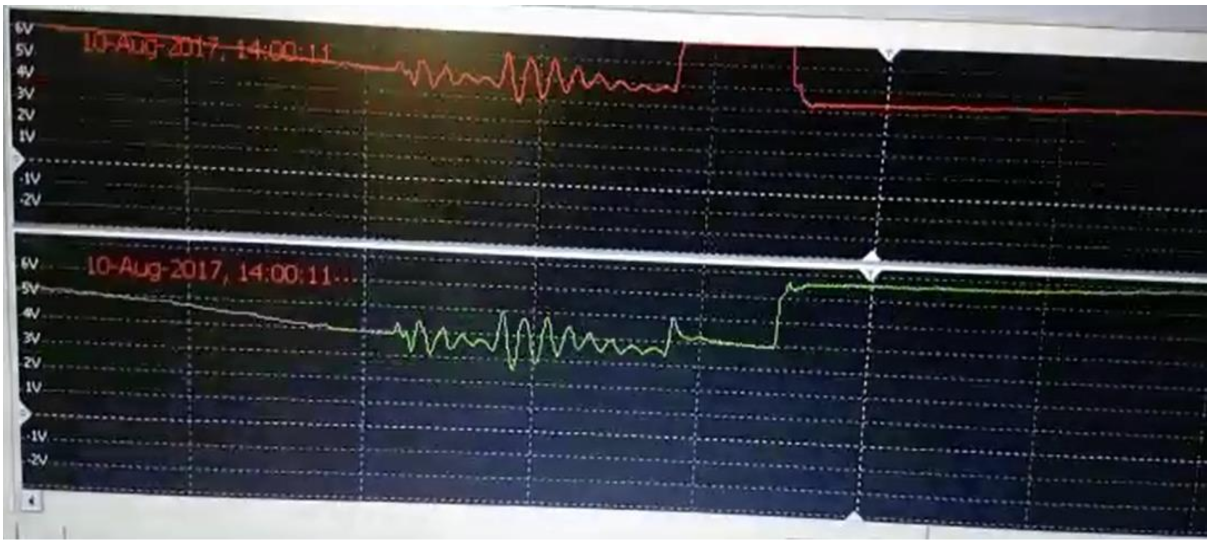
4.2.4 Experiment 3 results

In experiment 3, noise interference (EMI) was simulated using a welding machine on a Profibus network, with the aim of observing the behaviour of the network with specific focus on the scope waveform of each network device or node. Figures 4.14 to 4.17 indicate the distortion of the square wave of the entire network while welding at 80A and at 200A, respectively. The network was tested on different welding currents, but only the waveforms while welding at 80A and at 200A are shown, because the results of all the waveforms were exactly the same. The Y-axis represents the network voltage signal and the X-axis represent the number of bits passing through per second:



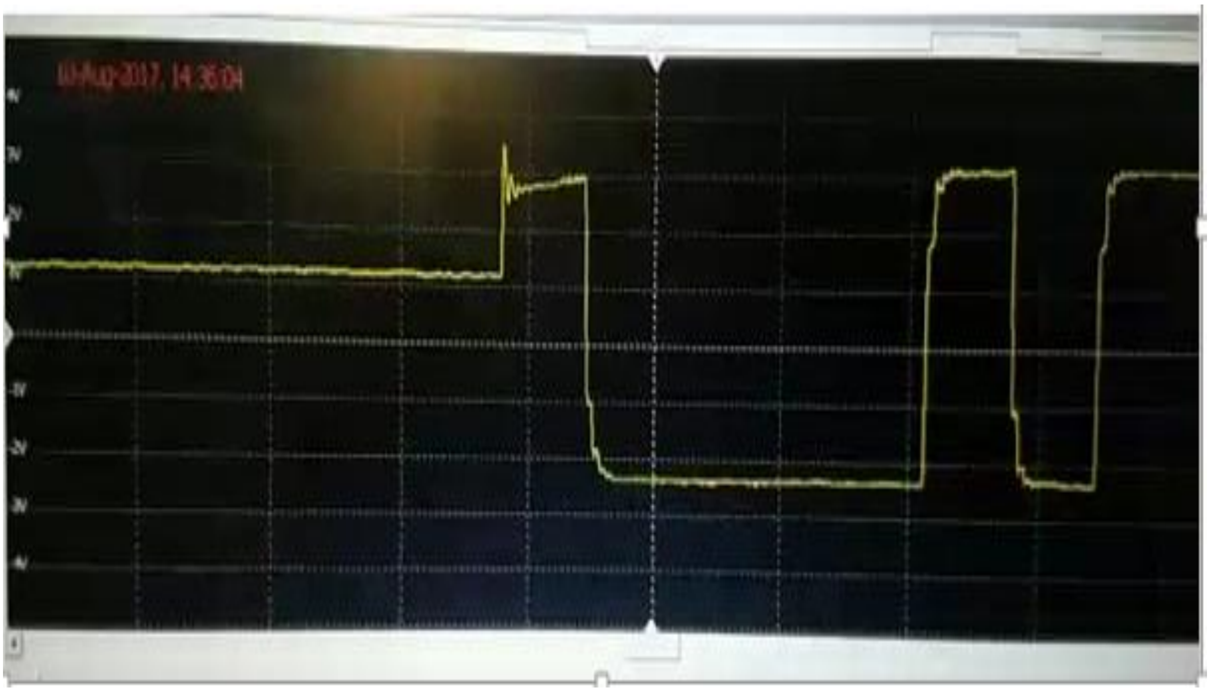
Note: X-axis represents time in 2.5µSec/div, and Y-axis represents1V/div (volts).

Figure 4.14: A&B data scope wave (welding at 80A) (Tubatse plant, 2017)



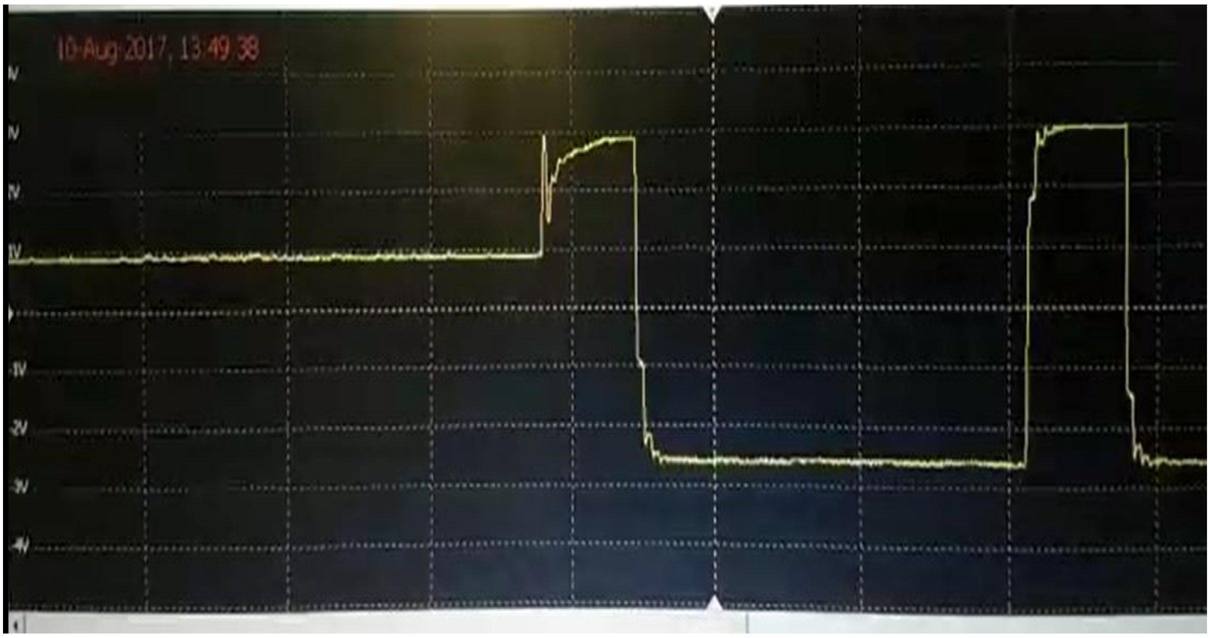
Note: X-axis represents time in 2.5µSec/div, and Y-axis represents 1V/div (volts).

Figure 4.15: A&B data scope wave (welding at 200A) (Tubatse plant, 2017)



Note: X-axis represents time in 2.5µSec/div, and Y-axis represents 1V/div (volts).

Figure 4.16: A&B diff data scope wave (welding at 80A) (Tubatse plant, 2017)



Note: X-axis represents time in 2.5µSec/div, and Y-axis represents 1V/div (volts).

Figure 4.17: A&B diff data scope wave (welding at 200A) (Tubatse plant, 2017)

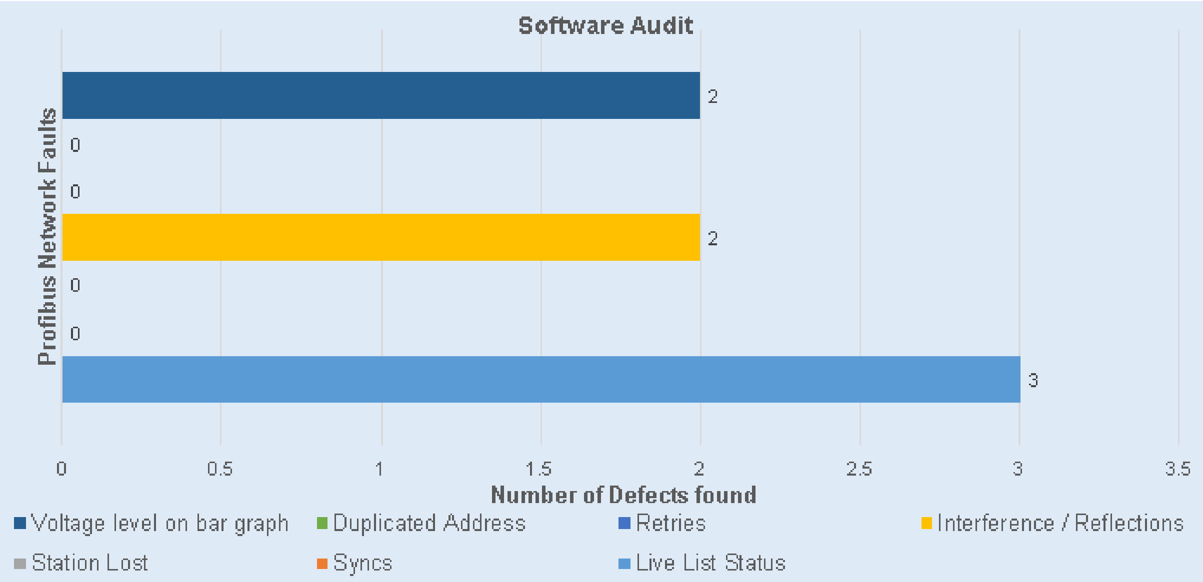


Figure 4.18: Network audit results for small test network with interference

4.2.5 Experiment 3 results analyses

From experiment 3 results, it could be observed that there was electromagnetic interference (EMI) when the Profibus cable was run next to high voltage carrying cables. There was also distortion in the square waveform as observed from the scope waveforms in Figure 4.14 to Figure 4.17 respectively.

The shape of the square waveform changed altogether, based on the voltage that was applied. The flowing electrical current did not change the waveform drastically even when it was stepped up (see Figure 4.19). The peak-to-peak voltage of the square wave changed. The transmitted message was corrupted.

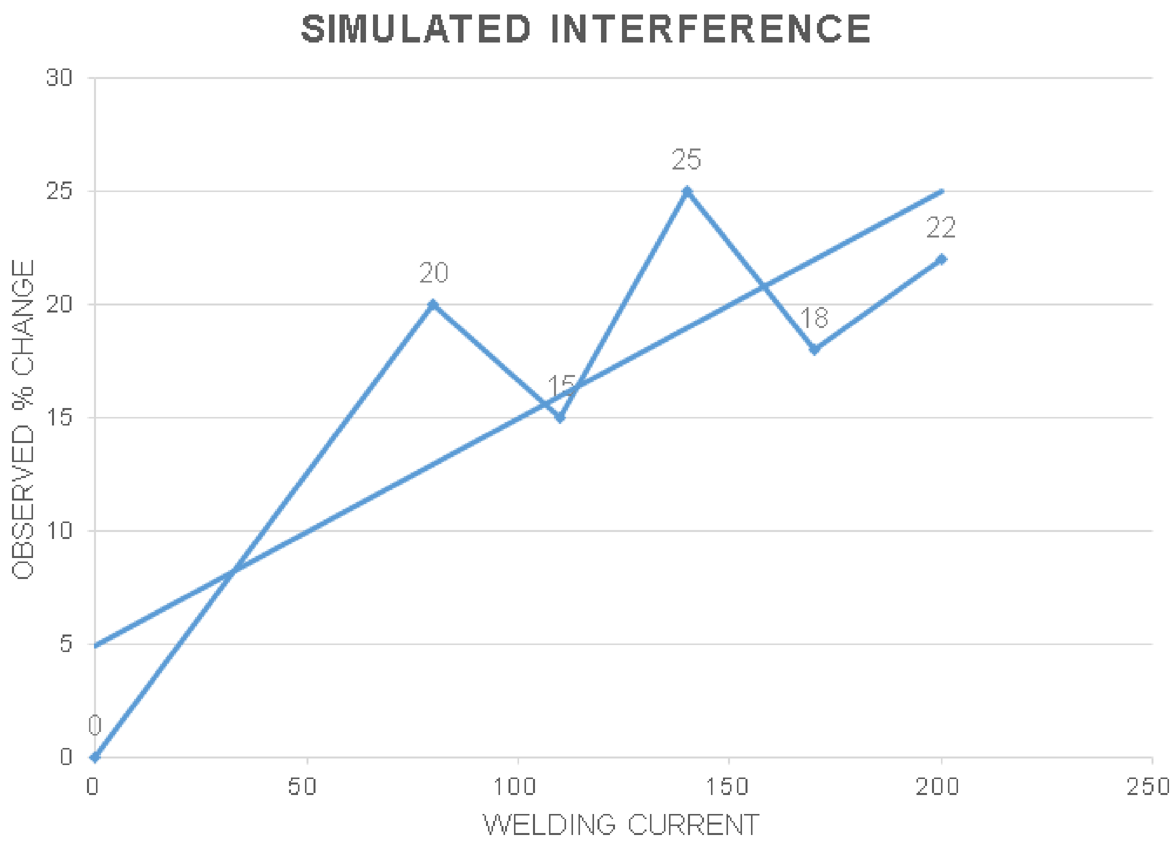


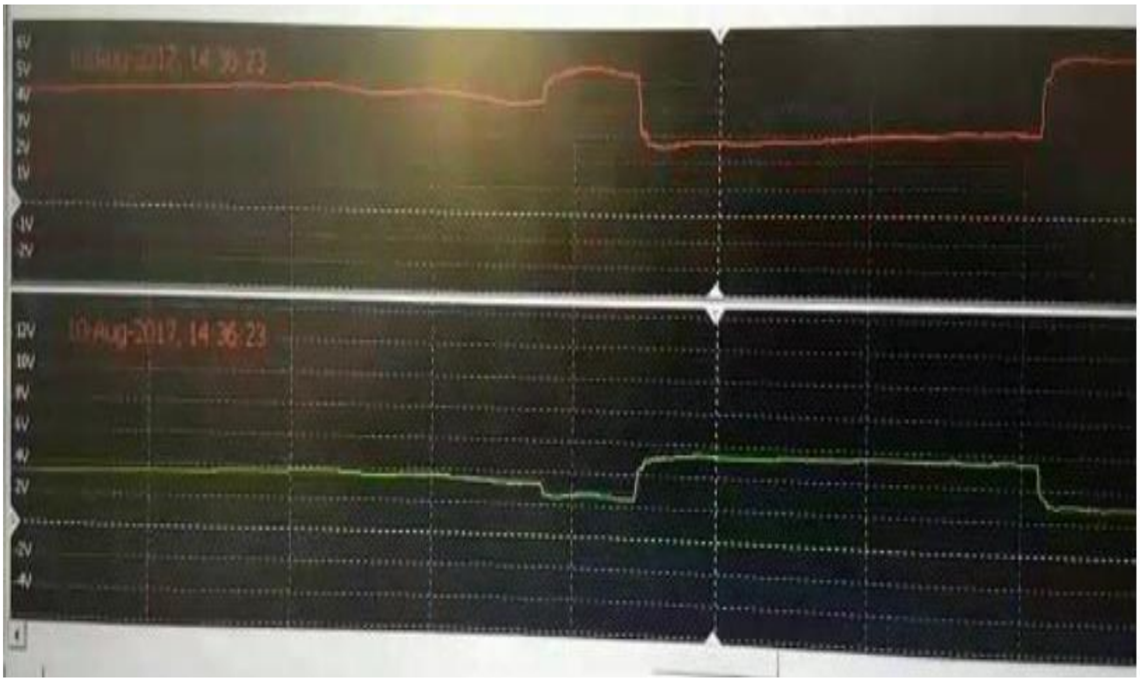
Figure 4.19: Simulated network interference by welding machine

This experiment was aimed at answering Research Question no.2 and no.4, as stated in Table 4.1, with the objective of proving that when the Profibus cable was run next to high voltage carrying cables, an electromagnetic interference (EMI) will be induced inside the Profibus cable, and it will change the binary coded message that was being transmitted at that particular moment.

It was also observed that the simulated current did not really change the amount of scope wave distortion. The changes ranged between 15% and 25% when welding with a 220V machine. There was no welding machine available with a higher voltage capacity, to test higher voltage levels.

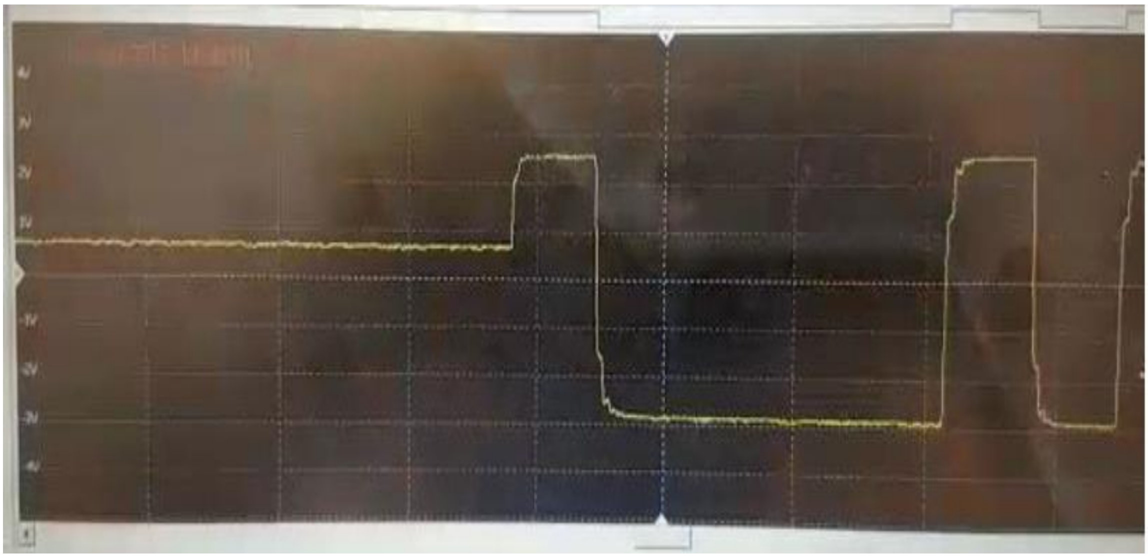
4.2.6 Experiment 4 results

In experiment 4, noise interference (EMI) was injected into the Profibus network using a welding machine, but the shielding/screening on the network cable was removed from the earth potential or ground. The following scope waveforms show how the network was affected:



Note: X-axis represents time in 2.5µSec/div, and Y-axis represents 1V/div (volts).

Figure 4.20: A&B unearthed screening (Tubatse plant, 2017)



Note: X-axis represents time in 2.5µSec/div, and Y-axis represents 1V/div (volts).

Figure 4.21: A&B diff unearthed screening (Tubatse plant, 2017)

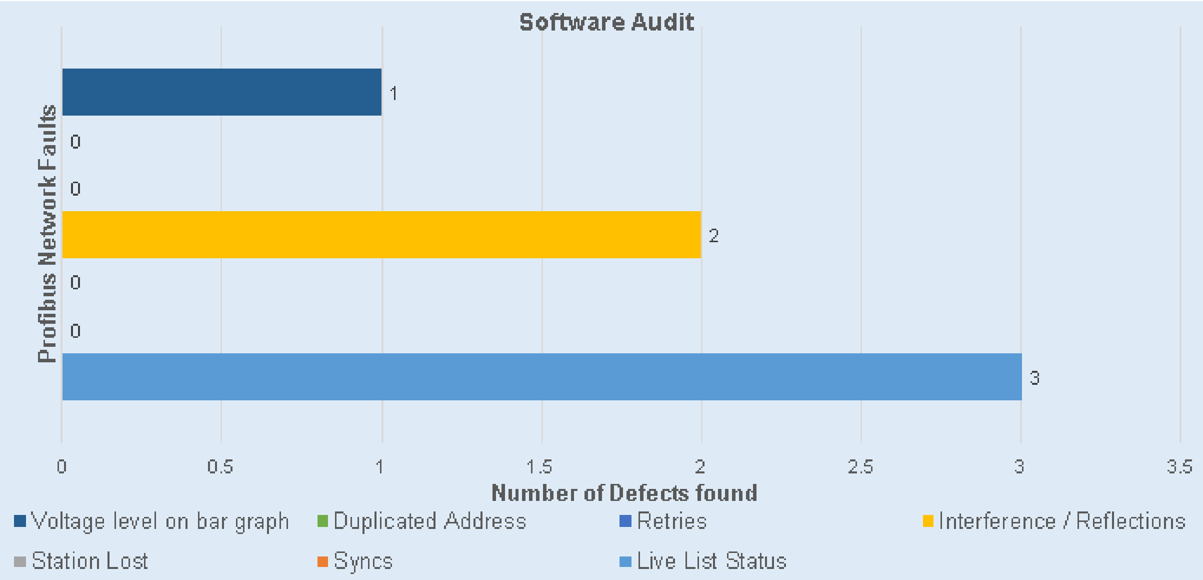


Figure 4.22: Network audit results for small test network with screen removed

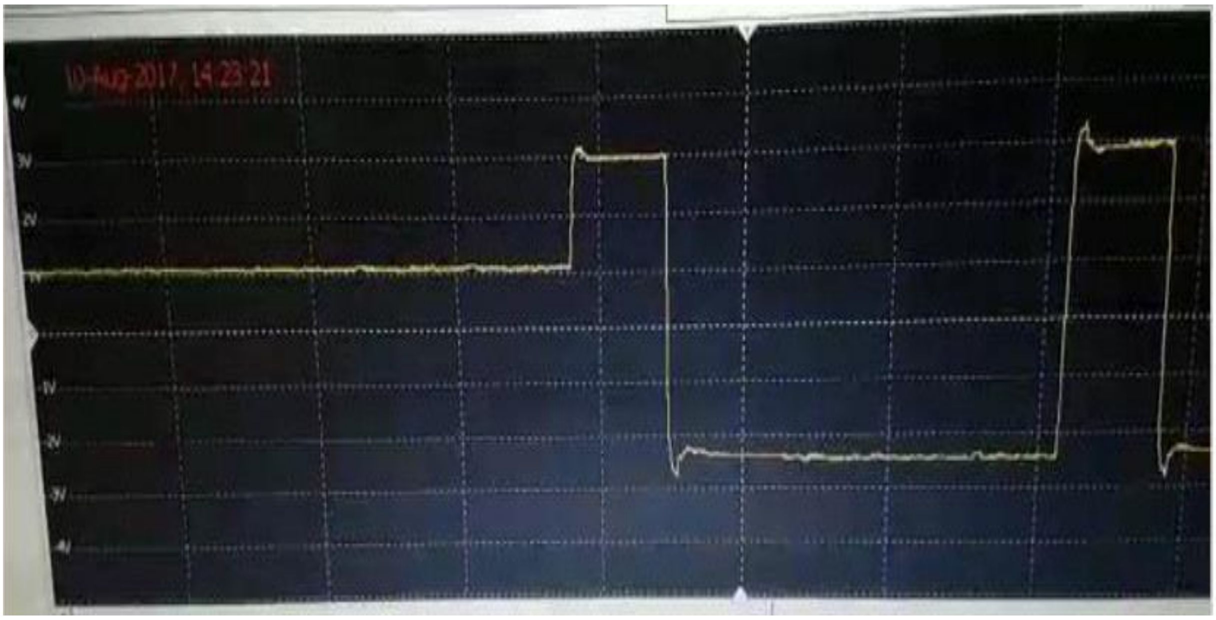
4.2.7 Experiment 4 results analyses

From experiment 4 results, the following could be observed:

- The edges of the square waves formed an oval or round shape.
- The square wave shape went from square towards a straight line shape (refer to the B or green waveform in Figure 4.28).
- The flowing electrical current did not change the waveform drastically when current was simulated on different levels.
- The peak-to-peak voltage of the square wave changed.
- The transmitted message was corrupted.

4.2.8 Experiment 5 results

In experiment 5, the Profibus cable was substituted with a different cable. A shielded twin pair cable was used. A welding machine was used to simulate interference into Profibus network and the network report was generated as well. The following results were obtained:



Note: X-axis represents time in 2.5µSec/div, and Y-axis represents 1V/div (volts).

Figure 4.23: A&B Diff using the shielded twin flex cable on Profibus network (Tubatse plant, 2017)

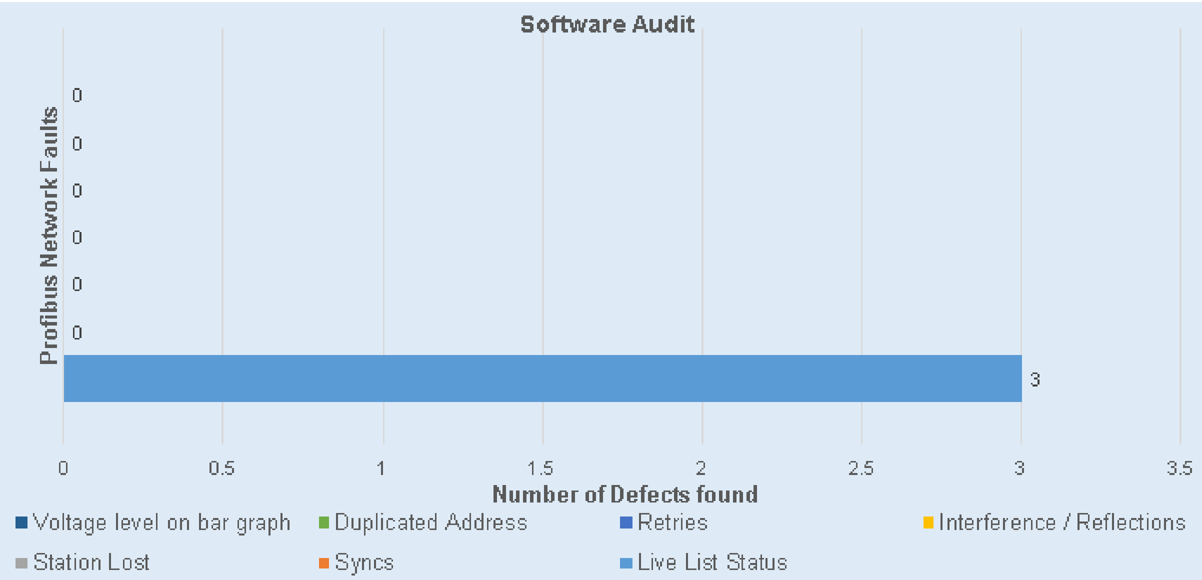


Figure 4.24: Network audit results for small test network using twisted pair cable

4.2.9 Experiment 5 results analyses

The waveform showed very little interference. The network behaved more like when experiment 2 was conducted. The peak-to-peak voltage did not change. The transmitted message was not corrupted. The network master and all slaves were healthy. There were no illegal responses. None of the slaves caused syncs. None of the slaves caused retries. None of the slaves generated diagnostics while in data exchange. There were no lost station or slaves.

The results that were obtained from the twisted cable experiment actually indicated that another cable can be used to substitute the Profibus cable when interference is a problem on the network.

4.2.10 Simulation Experiment 1 results

The four signals that were supplied into the Profibus network remained unchanged, and appeared without any alteration when viewed from the output oscilloscope. As soon as the interference signal was applied, distortion to the original message was observed. It could also be seen that as the noise power was increased, distortion increased more in amplitude rather than in the time domain. The following waveforms illustrate how the system behaved from when there was no simulated interference until when maximum interference was simulated using Simulink:

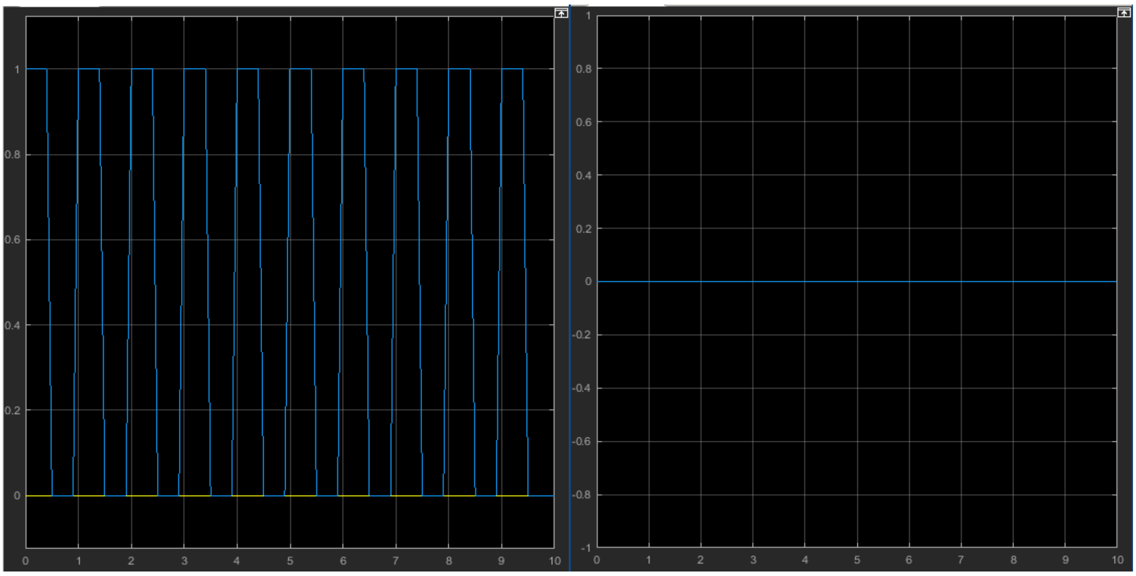


Figure 4.25: Signals 1 and 2 viewed from the output oscilloscope (no interference)

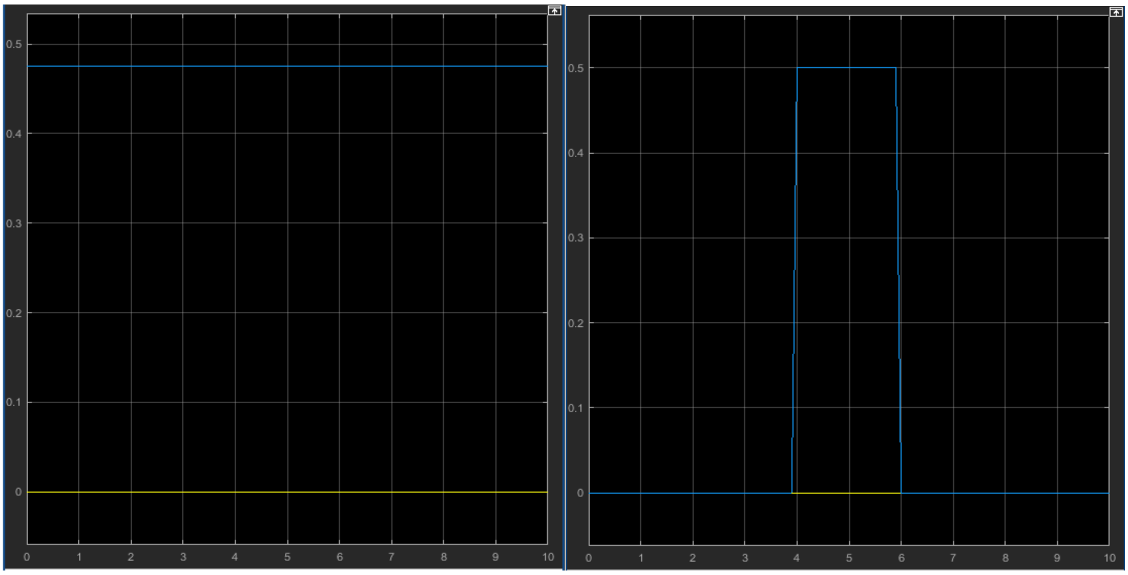


Figure 4.26: Signals 3 and 4 viewed from the output oscilloscope (no interference)

Figure 4.27 indicates the waveform of the four singals combined, as viewed from the output oscilloscope. It can also be seen that the signals were unaltered and can be dipicted separately from the graph. The blue square wave represents signal 1, the orange wave represents the signal 2, the green wave represents signal 3, and the purple wave represents signal 4.

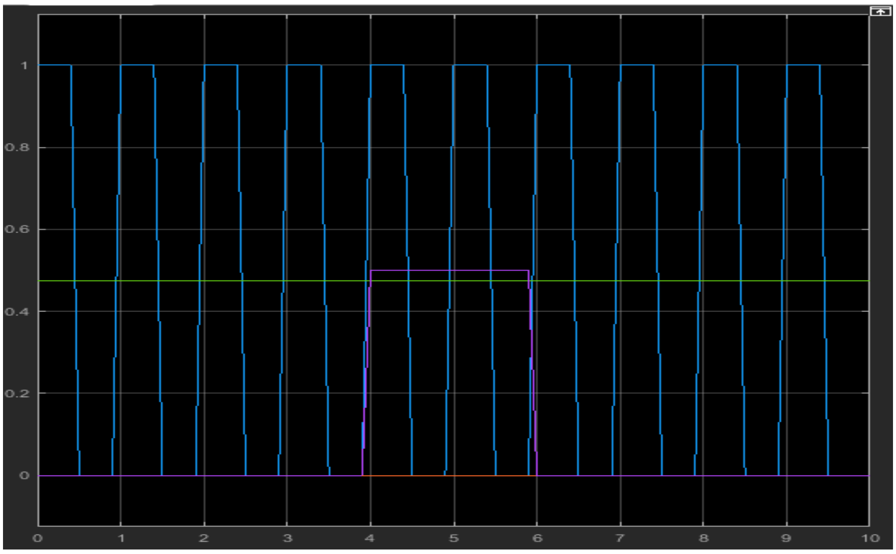


Figure 4.27: Combined signals viewed from the output oscilloscope (no interference)

Figures 4.28 to 4.30 illustrate how the system behaved when interefence was induced. The noise power was induced in a linear fashion, as outlined in the preceeding chapter, from the noise power of 1 to 6.

The following waveforms are for signal 1 only:

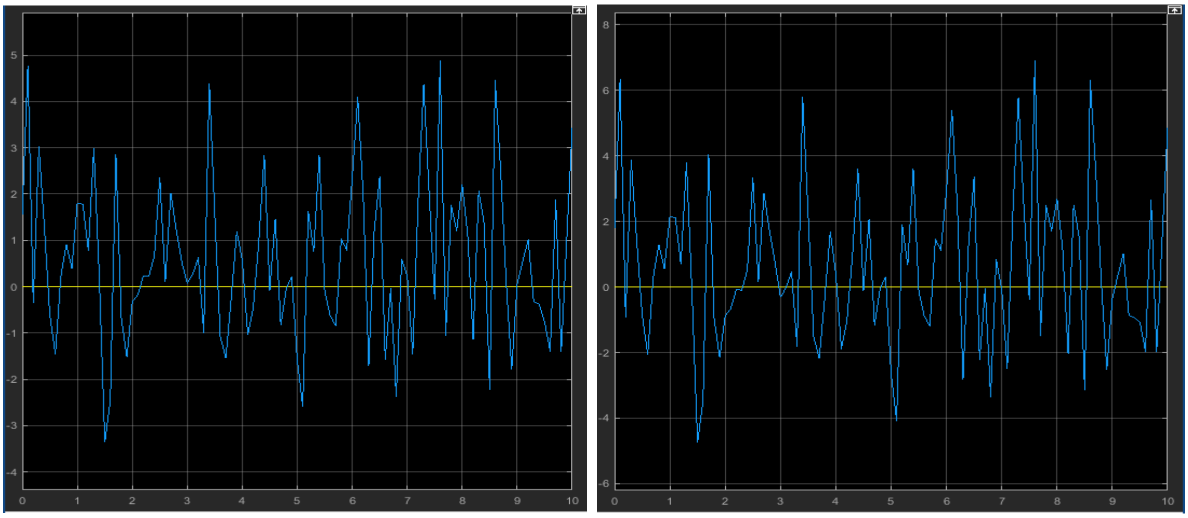


Figure 4.28: Signal 1 viewed from the output oscilloscope (noise power 1 & 2)

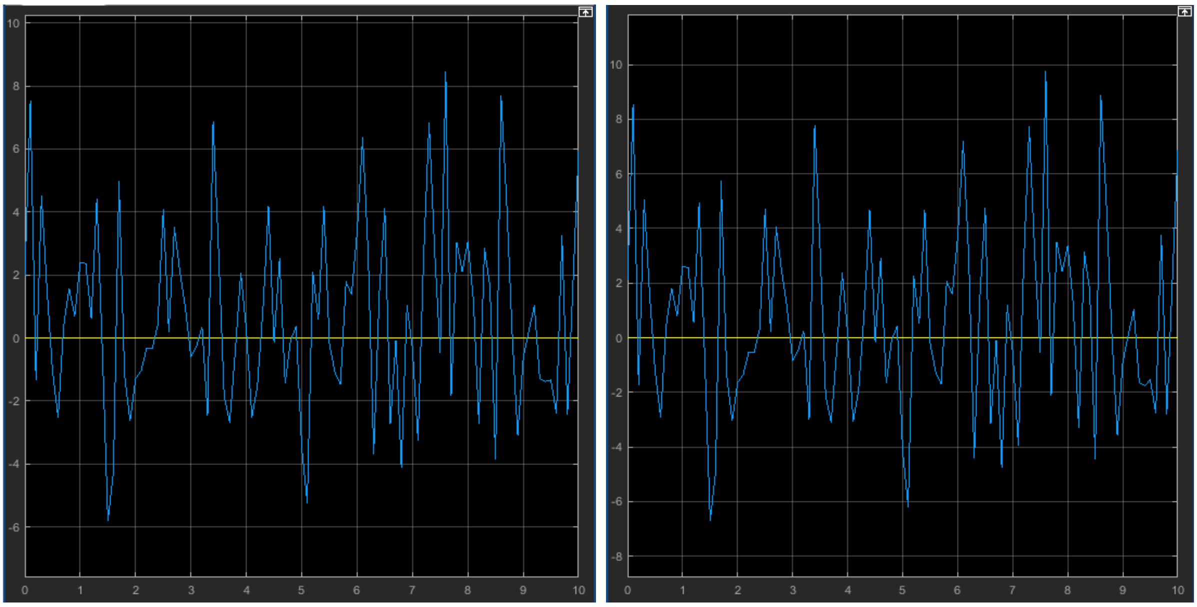


Figure 4.29: Signal 1 viewed from the output oscilloscope (noise power 3 & 4)

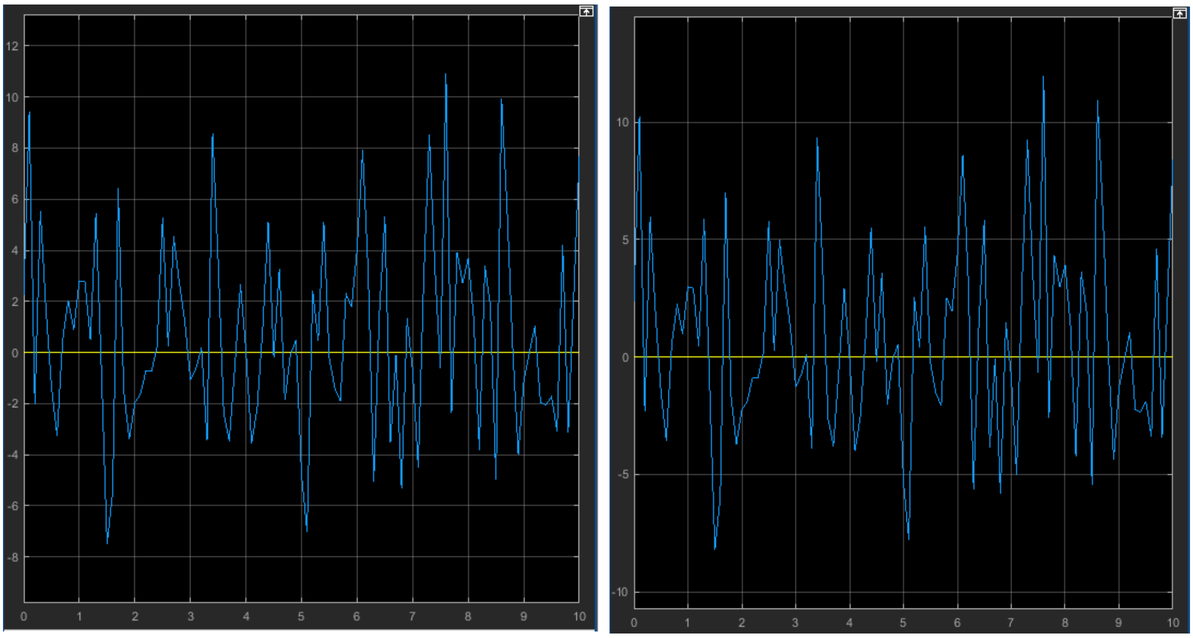


Figure 4.30: Signal 1 viewed from the output oscilloscope (noise power 5 & 6)

All six signals behaved the same, and for this experiment only the oscilloscope waveforms of the first signal are shown. The waveforms of the combined signals also behaved in a similar fashion, and only the waveforms with the minimum and maximum noise power are shown:

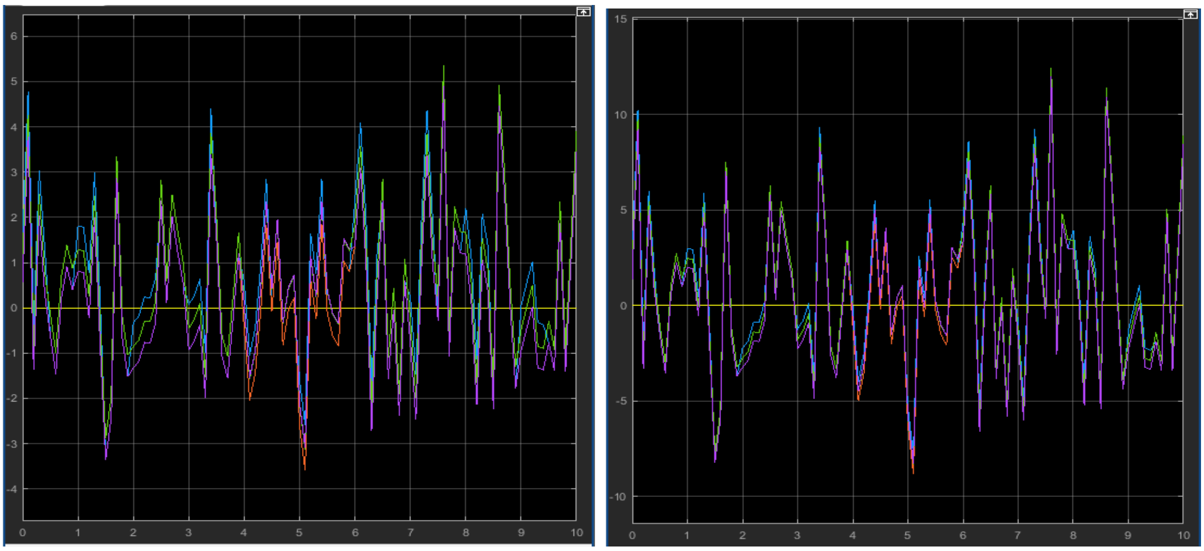


Figure 4.31: Combined signals viewed from the output oscilloscope (with interference)

4.2.11 Simulation Experiment 1 results analyses

The interpretations of the signals when simulated with the noise power from low margin to the highest margin (i.e. from the noise power of 1 to 6) as set out in experiment no.2, shows a linear increase in the amplitude of the distorted waveform. Figure 4.32, below, shows the line chart graph of the distortion of the command signals versus the noise power that was simulated by the noise generator block within the Simulink:

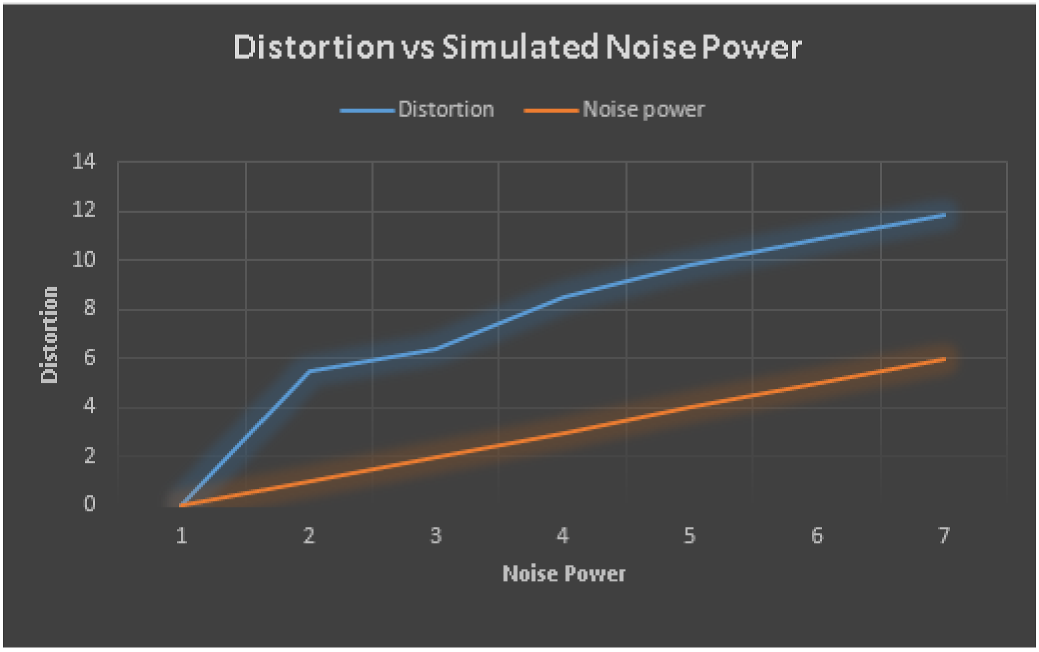


Figure 4.32: Distortion versus noise power

It can be concluded that as the degree of interference increases in the Profibus system, the message signal that is sent through the system becomes more and more corrupted. This will create instabilities of the entire systems.

4.3 Conclusion

This chapter discussed the results of the experiments that were conducted in the methodology chapter. The results of all five experiments were analysed, and the research questions were answered. Both the research questions and objectives of the study were met. Chapter 5 will discuss the conclusion and recommendations for possible future research, if necessary.

CHAPTER 5: RESEARCH SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 Introduction

In Chapter 4, an analysis of the research findings were carried out. Images of the results were shown, their data were extracted and tabulated, compared to standards as discussed in the literature in Chapter 2, and then analysed. In this chapter, a summary of the whole dissertation, conclusions of the research, a discussion of the limitations of the study, and recommendations for future research, are presented.

In Chapter 1, the problem statement that led to the need to conduct this research, was discussed. It was deduced that the industrial automation network at Samancor Ferrochrome in Limpopo was so unstable that it created financial losses for the company. This was due to downtime experienced at the pelletizing and sintering plant (PSP), because of the Profibus network instability.

The research questions that sufficed were the following:

- What are the causes of network failure on the Samancor Profibus network?
- Are there any interferences that might be introduced into the Profibus network?
- If there are such interferences, to what degree is it interference?
- What is the performance of the network when another network cable is used on the PLC being used?
- How does the signal strength/voltage of the network compare to other stand-alone networks?

In Chapter 1, an overview of the research outline was presented. The background to our study formulated the research problem. Research questions and the method to be used for the research were outlined in this chapter. Further to the research questions a dissertation roadmap was formulated. The study objectives came into existence and they were formulated as follows.

- To evaluate the performance of the network using standard testing determine methods to see if there are any interferences that might be introduced into the Profibus network.
- To compare different network cables that can be used on Profibus network PLC.
- To measure whether the signal strength/voltage of the network is sufficient.
- To test and simulate the network using parameters in objectives 1 and 2, and compare with the physical performance of the network.

In Chapter 2, a review of the literature regarding Samancor's automation network was conducted. Special focus was given to the overview of how automation was conducted at Samancor Ferrochrome. It was revealed, in this chapter, that Tubatse Ferrochrome opted to standardise on the Siemens PLC system which was controlled at the central place called the CSO (control systems office) with the type of communications network used as the Profibus DP. The Profibus system was discussed in detail, and the literature regarding Profibus DP was perused. Chapter 2 also discussed related work that was conducted by other researchers in the past regarding Profibus DP as used in industrial communications.

In Chapter 3, the methodology used to conduct the research (quantitative) was explained. This methodology involved a number of experiments, simulations and standards audits/inspections in the plant that triggered the need for the research to be conducted. To answer the research questions, five experiments were carried out.

Experiment scenario 1 was the plant network audit experiment. With this experiment special focus was laid on two types of inspections: the software configuration audit and the installation standards audit.

For experiment 2, a stand-alone Profibus network was built according to the installation rule standards of Profibus, and the network report was generated while the network was without any interference. This experiment was conducted for reference purposes, because it was known what data was expected and how the network would behave when the network was healthy. This practice was referred to as benchmarking.

For experiment 3, the researcher took a 220V welding machine and wrapped its current carrying cables around the Profibus cables of the same stand-alone network, and started welding. Network reports were generated while welding at different welding current. The welding machine was equipped with a potentiometer were current was increased at linear intervals of10A.

In this experiment only plots/scope wave while welding at 80A and 200A are shown, because the results were the same for all current magnitude that were used for tests. The researcher plotted results at 80A and 200A because they were the minimum and maximum welding currents that he could weld with. Below 80A, the welding machine was getting sticky, and he was struggling to weld.

For experiment 4, he carried out the same exercise as in experiment 2, except that he removed the shielding of the Profibus cable from the earth potential/ground.

For experiment 5, he also carried out the same exercise as in experiment 2, except that he substituted the Profibus cable with a shielded twin pair cable with the intention of seeing whether the Profibus cable is the best cable to use on this kind of a network.

For the simulation experiment, the researcher modelled the live network plant network using Simulink software. The replica of the plant network was generated using the Simulink software and he generated four signals which were simulated and analysed without interference, and also analysed with interference induced into the system.

In Chapter 4**,** analyses of the experimental findings were done. The inspection sheet was created and used to analyse the network. The checklist used for inspection was created from the literature reviewed in Chapter 2.

5.2 Conclusions and recommendations

The study was aimed at closing the gap regarding network interference. After conducting all the experiments for this research, and after running all the tests and analysing the results, the following recommendations pertaining to Profibus network installation and maintenance was observed: EMI has severe consequences on the Profibus cable. Overall, the shielded cable performed far better than the unshielded, in terms of electromagnetic interference. It is recommended that shielding of cables is necessary to prevent EMI. Moreover, from the results of experiment 5, it is suggested that further study be conducted on a communication cable that can be immune to electromagnetic interference but still possess all the qualities of the Profibus cable.

Another topic that needs to be researched would be one that will quantify the amount of interference that takes place in the Profibus network, with reference to different voltage sources. Experiments need to be conducted where the simulated interference to the network is at different voltage levels, and not only at different current levels.

KEY TERMS

Network evaluation; Network optimisation; Real time network performance; Profibus failures; Communication errors, Communication faults; Network interference; Industrial network glitch; Network performance evaluation; Decentralised peripherals; Industrial communication; Communication failures.

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Appendix A

Afrilek
163 Van Der Bijl Str
c/o Van Der Bijl and Flemming
Meadowdale
Germiston
011-552 8113

Company / customer	Tubatse
Project description	Network Documentation
Job No.	1302

Created on 2012/12/13

Edit date 2013/06/03 by (short name) KeeganM Number of pages 30

No.	Revision Description	Rev No.	Creator
1	Update after site visit	04	KeeganM
2	Update after Comments on 29/03 /2013	03	KeeganM
3	Update after Comments	02	KeeganM
4	Issued For Approval	01	KeeganM

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Network Documentation
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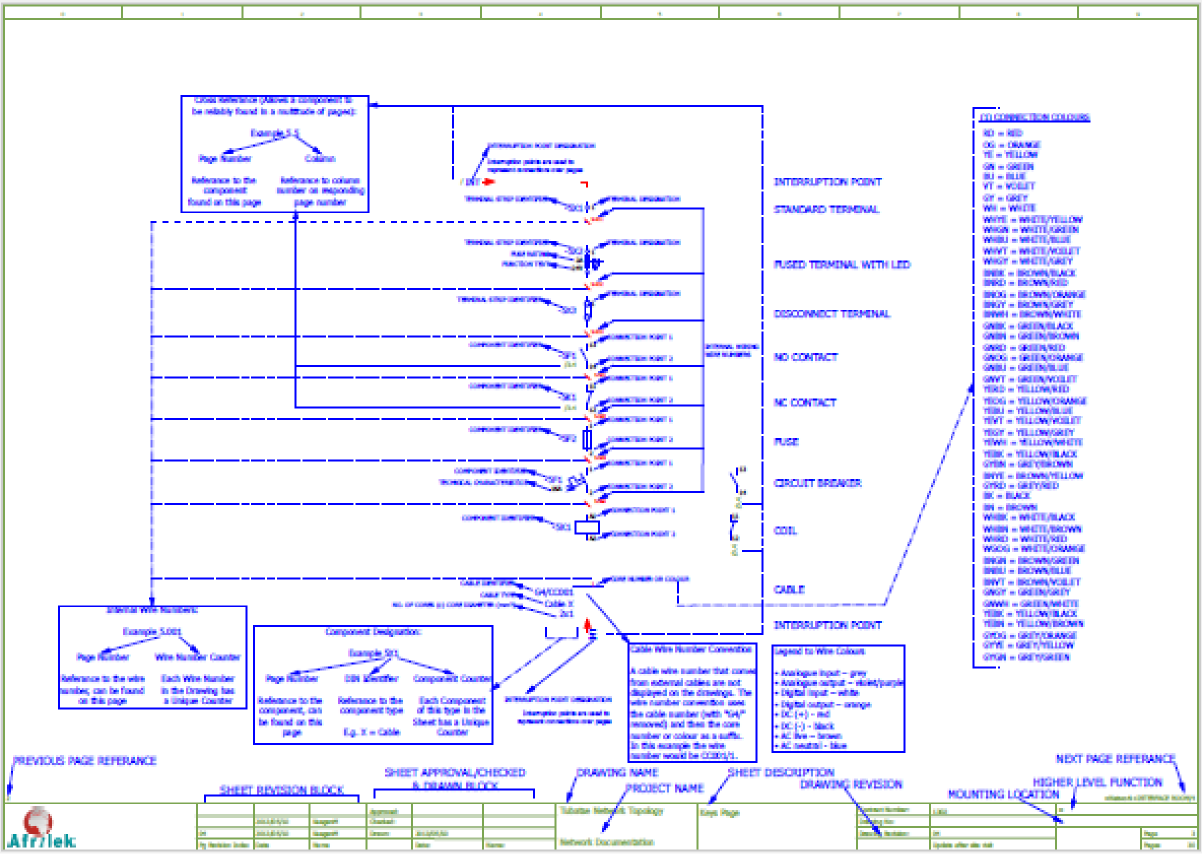
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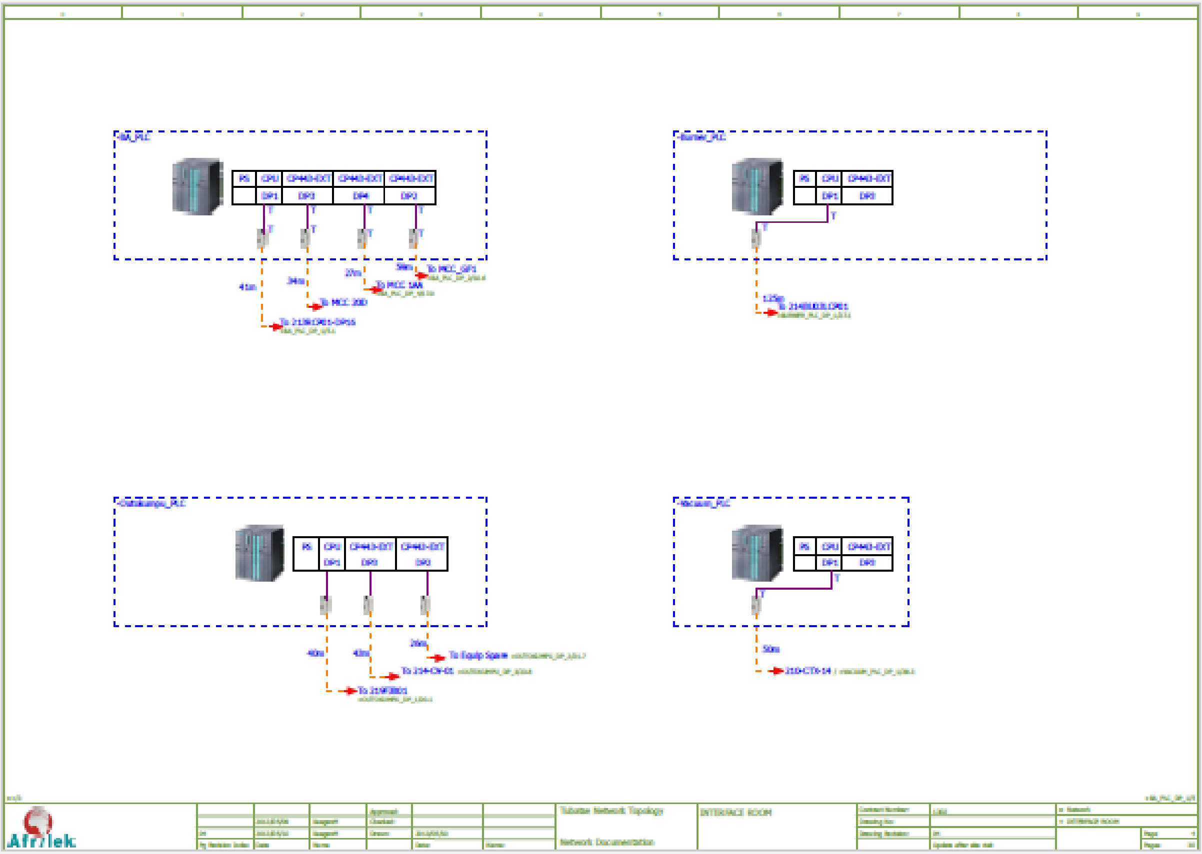
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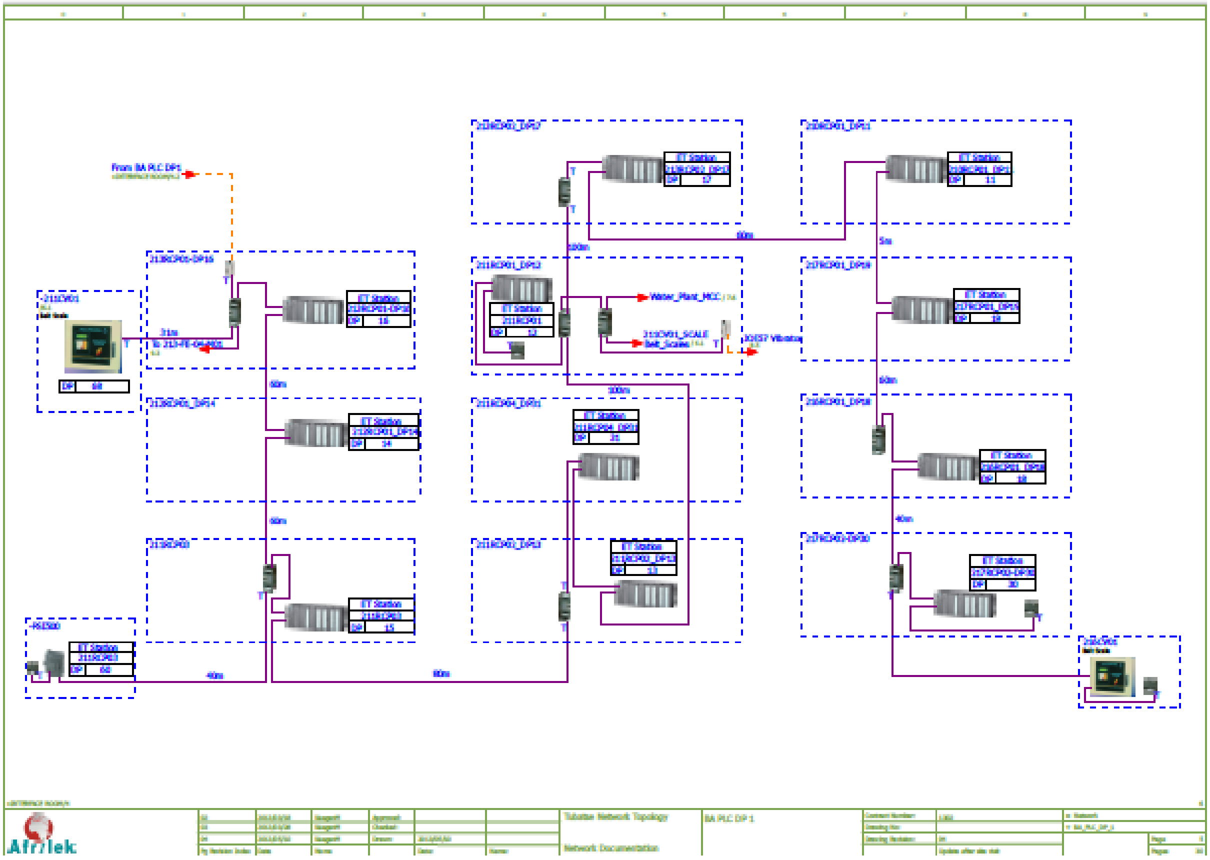

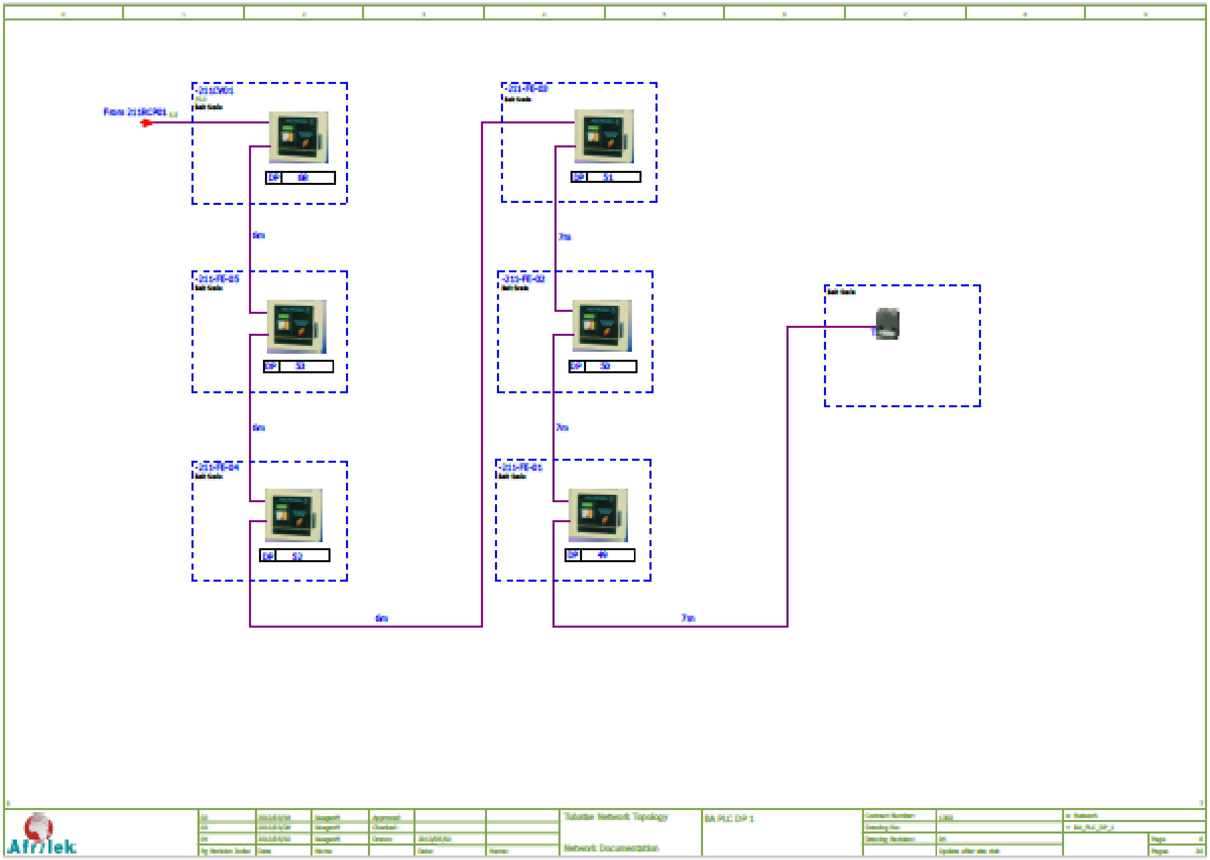

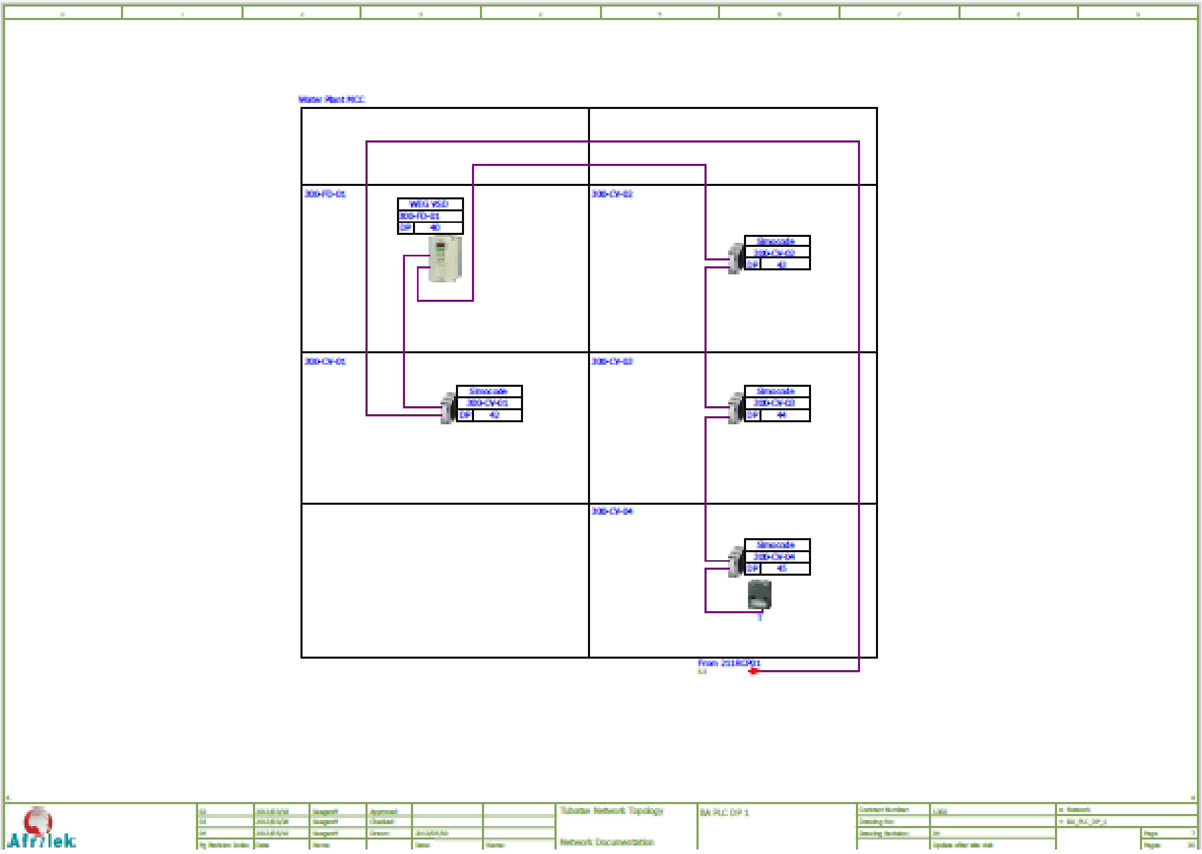
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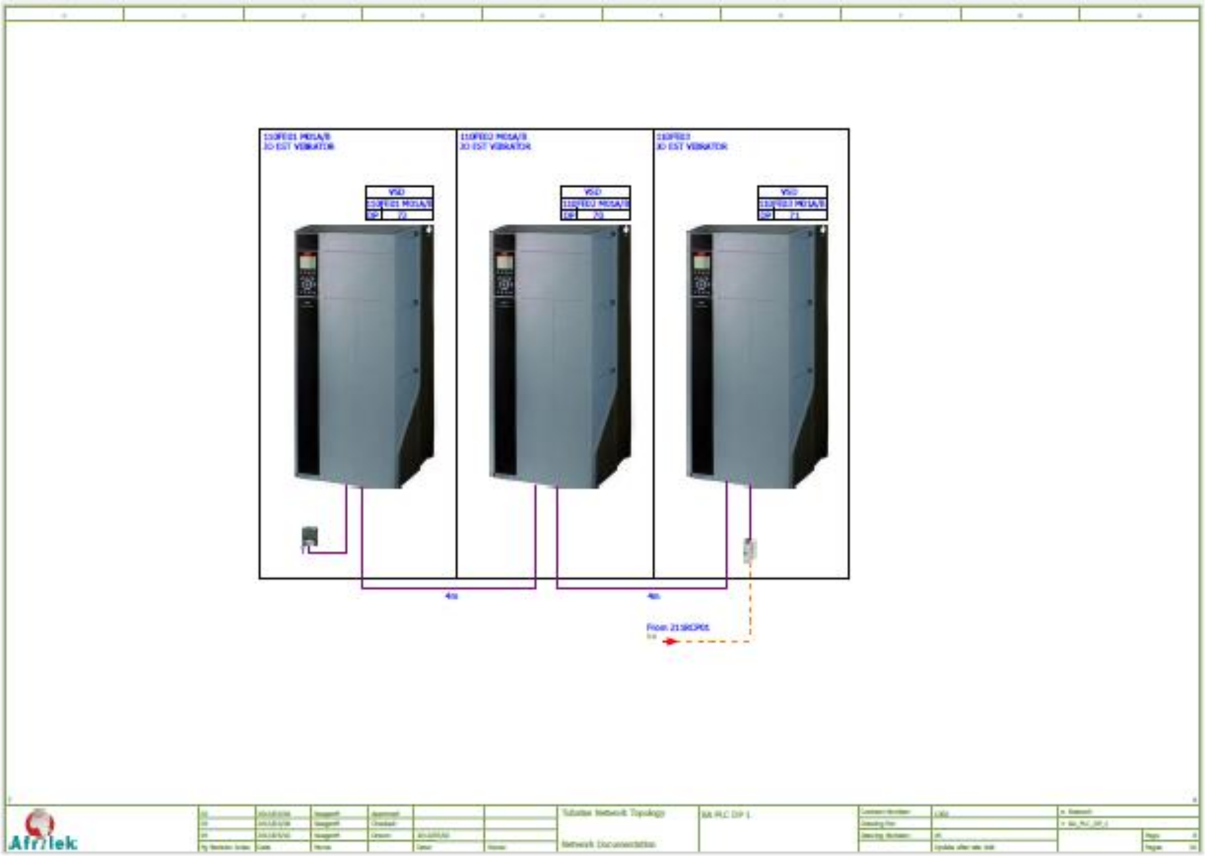
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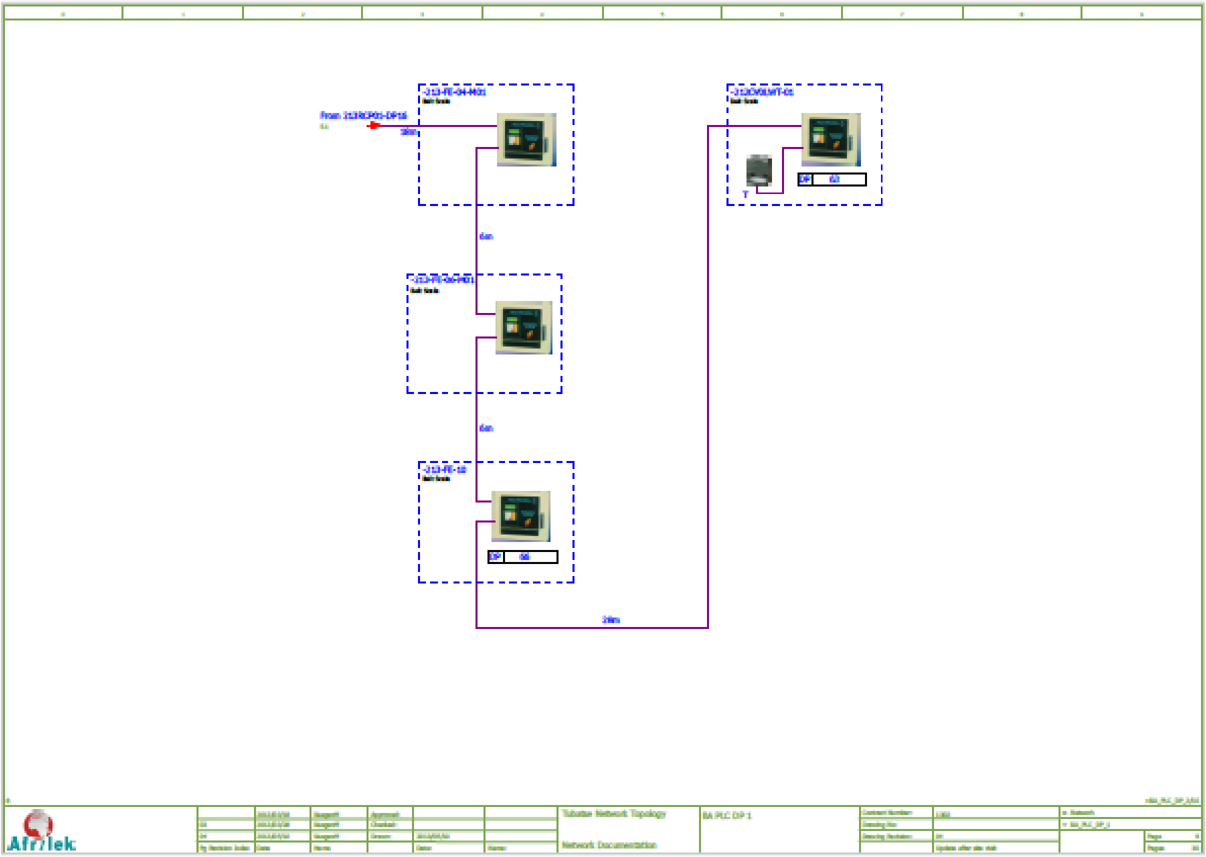

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Network Documentation
BA PLC DP 1

Appendix B

TUBATSE
THE HOME OF CHROME

Tubatse Chrome (Pty) Ltd

Registered Address:
R555, Main Road
Steelpoort, 1133
Postal Address:
Private Bag X504
Steelpoort, 1133
Telephone number: +27 (0) 13 230 8200
Facsimile number: +27 (0) 13 230 9401

September 27, 2016

Re: Permission for Patrick Amos Mahlangu (Student Number: 37029177)
To conduct research

Dear Sir/Madam

This letter serve to give permission to Patrick Amos Mahlangu permission to conduct his research dissertation in partial fulfilment for the degree of Magister Technologiae in Electrical Engineering at the University of South Africa.

Topic:

NETWORK OPTIMISATION

10/1/13

WC Murray
HR Specialist HR

Tubatse Chrome (Pty) Ltd
Human Resources Department
27 SEP 2016
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Steelpoort 1133
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NETWORK AUDIT			
Software Audit	**Number of defects found**	**Installation Standards Audit**	**Number of defects found**
Live list status		Minimum cable length of 1M between network devices.	
Syncs		Maximum segment length of 1000M	
Station lost		Earthing and/or shielding of the screen cable	
Interference / Reflections		Bending of the profibus cable	
Retries		Running of the profibus cable next to high voltage cables or power line or running the profibus cables in high voltage cable trays	
Duplicated address		Air separation distance between Profibus cables and power lines	
Voltage levels on bar graph		Redundant equipment	
		Illegal installation	
		Physical damage	
		Drawings	