Murdoch University Pilot Plant
Advanced Control Technology Upgrade

A report submitted to the School of Engineering and Energy, Murdoch University in partial fulfilment of the requirements for the degree of Bachelor of Engineering

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ABSTRACT

The Pilot Plant is an integral teaching facility for engineering students and as such the completion of the upgrade is critical. This thesis paper summarizes the work conducted in upgrading the hardware and software of the Murdoch University Pilot Plant. Due to the scope of the project not all aspects can be discussed in this paper. The paper is broken into nine chapters, and provides insight into the five stages of the project, being: Hardware installation, Commissioning, Coding, HMI display development and Excel communication. Each stage is unique and requires both technical and theoretical knowledge for completion.

The nature of a new operating system requires a large amount of documentation. Throughout the progression of each stage standard operating procedures for the configuration of Experion PKS applications were constructed. More technical characteristics of Experion PKS have been documented as functional descriptions while the new operating procedures have been detailed in student user guides. This includes user guides for operating the Pilot Plant via Station or Excel.

The pilot plant is considered a showcase for Instrumentation and Control engineering at Murdoch University. Consequently the Pilot Plant will be housed in the new engineering and science building so all can marvel in its glory. The move to the new building adds another level of complexity to this thesis, in that it is vital for the plant to be operational prior to the move and for that reason Excellent time management throughout the project was essential.
ACKNOWLEDGEMENTS

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**PP-0000**: P&IDs and Circuit diagrams
**PP-1000**: Datasheets and References
**PP-2000**: Software
**PP-3000**: Standard Operating Procedures
**PP-4000**: Functional Descriptions
**PP-5000**: User Guides
**PP-6000**: Commissioning Procedure
## Terminology and Acronyms

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<th>Name/Definition</th>
<th>Comments</th>
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<tr>
<td>ASM</td>
<td>Abnormal Situation Management Consortium.</td>
<td>Organization that have conducted extensive research in the field of Abnormal Event Guidance Information Systems</td>
</tr>
<tr>
<td>CEE</td>
<td>Control Execution Environment</td>
<td>Is the environment in which the user application executes in the C300</td>
</tr>
<tr>
<td>CM</td>
<td>Control Module</td>
<td>Environment which holds Function Block code – integrates plant data to the C300</td>
</tr>
<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
<td>Central Processor for C300 controller</td>
</tr>
<tr>
<td>CSTR</td>
<td>Continually Stirred Tank Reactor</td>
<td>Name of a vessel that consists of an agitator and where reaction may take place within.</td>
</tr>
<tr>
<td>C16</td>
<td>16-bit signed integer</td>
<td>-32767 to 32768</td>
</tr>
<tr>
<td>C300</td>
<td>C300 Controller</td>
<td>The CPU in the controller executes the CEE cyclically (50ms – 2000ms)</td>
</tr>
<tr>
<td>Data link Layer</td>
<td>Layer 2 of the OSI Model that is media-independent, and functions above Layer 1 (Physical Layer).</td>
<td>Defines protocols for data packets and how they are transmitted between networking devices. Includes two sub layers: Medium Access Control (MAC), and Logical-Link Control (LLC).</td>
</tr>
<tr>
<td>DCS</td>
<td>Distributed Control System</td>
<td></td>
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<tr>
<td>Ethernet</td>
<td>Lan protocol defined by IEEE 802.3 networking standard (physical and data link layers). Used CSMA/CD access method at a variety of speeds and using several different media</td>
<td>10 or 100 Mbps, Baseband network that uses various media (twisted pair, thick coax, thin coax, or fiber optic cable).</td>
</tr>
<tr>
<td>Ethernet/MODBUS Bridge</td>
<td>A hardware device that serves as an interface between serial MODBUS RTU devices and host applications using MODBUS/TCP protocol</td>
<td>Most bridges support sub-addressing for multiple devices connected to its serial RS-485 port</td>
</tr>
<tr>
<td>FB</td>
<td>Function Block</td>
<td>Elements used to construct control sequences</td>
</tr>
<tr>
<td>FTE</td>
<td>Fault Tolerant Ethernet</td>
<td>Honeywells proprietary Ethernet network between Experion and C series controllers</td>
</tr>
<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
<td></td>
</tr>
<tr>
<td>Hub</td>
<td>A hardware device with multiple ports enabling one device to be connected to several others</td>
<td>A hub forwards all messages on one of its ports to all of its other ports with no isolation between devices.</td>
</tr>
<tr>
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</tr>
<tr>
<td>IEEEFP</td>
<td>IEEE Standard single precision floating point number</td>
<td></td>
</tr>
<tr>
<td>IO</td>
<td>Input Output</td>
<td></td>
</tr>
<tr>
<td>IOM</td>
<td>Input / Output Module</td>
<td>Honeywell’s IO Module communicating to the C300 over the IOLink</td>
</tr>
<tr>
<td>IP Address</td>
<td>Internet Protocol Address</td>
<td>An IP address is a software address consisting of a 32 bit number, written as a 4 ‘octets’ (eight bits, translating to integers from 0 to 255) separated by periods. (eg, 134.115.133.172)</td>
</tr>
<tr>
<td>MAC Address</td>
<td>MAC coded ID</td>
<td>A Data Link layer address also known as a hardware address, physical address. This address is static and thus ‘burned-in’ to the product when it is manufactured.</td>
</tr>
<tr>
<td>MODBUS/TCP or MODBUS TCP/IP</td>
<td>Variant of the MODBUS PROTOCOL</td>
<td>MODBUS/TCP is a variant of the MODBUS RTU protocol used with RS232/RS-485 mediums. The MODBUS/TCP encapsulates MODBUS RTU frames in TCP frames for transport over an Ethernet network.</td>
</tr>
<tr>
<td>MSEDE</td>
<td>Microsoft Excel Data Exchange</td>
<td></td>
</tr>
<tr>
<td>OSI 7-Layer Model</td>
<td>Open System Interconnection Reference Model</td>
<td>The OSI model is established by the International Standards Organization (ISO) and used to enable computer communications using disparate media and protocols.</td>
</tr>
<tr>
<td>Packet</td>
<td>A bit sequence that is transmitted as an entity on a network</td>
<td></td>
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<tr>
<td>PCDI</td>
<td>Peer Control Data Interface</td>
<td>Special type of function block configured for MODBUS communication</td>
</tr>
<tr>
<td>PDU</td>
<td>Protocol Data Unit</td>
<td></td>
</tr>
<tr>
<td>PID</td>
<td>Proportional Integral Derivative Controller</td>
<td>Classical control algorithm</td>
</tr>
<tr>
<td>PLC</td>
<td>Programmable Logic Controller</td>
<td></td>
</tr>
<tr>
<td>Protocol</td>
<td>A system of rules for communication over a network.</td>
<td></td>
</tr>
<tr>
<td>P&amp;ID</td>
<td>Piping and Instrumentation Diagram</td>
<td></td>
</tr>
<tr>
<td>RTD</td>
<td>Resistive Thermal Detector or Resistive Temperature Detector</td>
<td>Instrument used to sense temperature through resistivity. Traditionally a 4-20ma / 1 -5v signal.</td>
</tr>
<tr>
<td>Name / Acronym</td>
<td>Name/Definition</td>
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<tr>
<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
<td></td>
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<tr>
<td>SCM</td>
<td>Sequential Control Module</td>
<td></td>
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<tr>
<td>SOP</td>
<td>Standard Operating Procedure Document</td>
<td></td>
</tr>
<tr>
<td>Switch</td>
<td>A multi-port Ethernet device that switches traffic between two or more network segments on an address-selective basis. These are also known as switching hubs.</td>
<td>An Ethernet switch is similar to a hub but differs in that it automatically determines and remembers where an Ethernet device is located and routes messages only through the appropriate ports.</td>
</tr>
<tr>
<td>S16B</td>
<td>16-bit signed integer</td>
<td>-32767 to 32768</td>
</tr>
<tr>
<td>TCP/IP</td>
<td>Transport Control Protocol/Internet Protocol</td>
<td>Transmission Control Protocol (TCP) operates at the Transport Layer of the OSI Model. The protocol manages connections between computers. Internet Protocol (IP) operates at the Network Layer of the OSI Model (one layer below TCP), the protocol defines how data is addressed (source/destination)</td>
</tr>
<tr>
<td>U16B</td>
<td>Unsigned 16-Bit integer</td>
<td>0 to 65535</td>
</tr>
<tr>
<td>VFD/VSD</td>
<td>Variable Frequency Drive / Variable Speed Drive</td>
<td></td>
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CHAPTER ONE: INTRODUCTION

1.1 Background

1.1.1 The Pilot Plant

The Murdoch University Pilot Plant was constructed in 1998 by Control & Thermal Engineering. At the time its use of Programmable Logic Controllers (PLC), Variable Frequency Drives and Honeywell’s Station software reflected some of the advance technologies that industry had to offer.

The Pilot Plant was initially designed to simulate the Digestion, Clarification and Precipitation stages of the Bayer process and was initially used as a teaching tool for engineering students to implement advance process control algorithms on industry grade equipment while simulating a real process.

The Supply tanks, Ball Mill, Ball Mill tank, bottoms of the Cyclone and Cyclone underflow tank simulates the Digestion stage. The Clarification stage is simulated via the overflow of the Cyclone, the Lamella and Needle tank. The Precipitation stage is simulated via the three jacketed CSTR’s. This stage is located separate from the Digestion and Clarification stages to simulate the ‘white side’ of the process.

The Instrumentation in the plant consists of:

- 11 Magna Flow Meters
- 7 Differential Pressure Level Meters
- 4 Differential Pressure Density Meters
- 4 Resistive Thermal Detective (RTD) Temperature Sensors
- 8 Positive Displacement Pumps
- 1 Motor (Ball Mill)
- 8 Flow Control Valves
- 10 Solenoid Valves
- 9 Variable Frequency Drives (VFDs)

The initial communication architecture of the Pilot Plant consisted of a Supervisory Control and Data Acquisition (SCADA) arrangement including an Allen Bradley PLC5 and a Honeywell SCAN3000 server acting as the supervisory computing system. The server allowed read/write communication to multiple software programs. Default operation of the plant was through Honeywell’s Station software. Station provided students with pre configured display screens that offered plant wide selection of control loops. Each control loop consisted of a PID algorithm with parameter selection.

Students had the ability to read process variables from the server into Excel, apply generic and advance control strategies, and write operating points to the server to control pump speeds or valve positions.

1.1.2 The upgrade

The Pilot Plant has become a fundamental component in a number of the electrical engineering disciplines at Murdoch University, mainly due to its use of industry standard instrumentation, motors, variable speed drives and control abilities.

The upgrade in hardware and software was considered with the intention of keeping up with the advancements in technology and providing a facility for students to implement model based and advanced control schemes.

The upgrade will also provide a faster scan rate than the old PLC program. The previous configuration had a PLC scan time of two seconds and SCAN3000 had a refresh time of five seconds. As a consequence the data viewed in station and used for
automatic control in Excel had the potential of being up to seven seconds old. The upgrade to a Honeywell C300 controller provides a maximum 50ms CPU scan time.

The hardware upgrade includes:

- Honeywell’s C300 control hardware and following I/O modules:
  - 32 channel digital input module x 2
  - 32 channel digital output module x 2
  - 16 channel analog input module x 2
  - 16 channel analog output module x 1
- Danfoss FC102 Variable Frequency Drives (VFDs)
- MODBUS serial channel to communicate to VFDs
- MODBUS TCP to Serial RTU Bridge
- P&ID’s and wiring diagrams design.

The software upgrade includes:

- Honeywell Experion Process Knowledge System (PKS) software
- Station R310 HMI operator displays
- Microsoft Excel Data Exchange (MSEDE) server communication
- Excel 2007 communication with 1 second refresh rate.

In summary the old SCAN 3000 server and station is replaced with an Experion Process Knowledge System and the PLC5 replaced with a Honeywell C300 controller and associated hardware modules. The upgrade will allow for wireless instrumentation, Foundation Fieldbus instrumentation and MODBUS communications.
1.1.3 Review of upgrade

The upgrade to Honeywell’s Experion and C300 has been an ongoing project. This thesis continues directly from the work conducted by students in ENG454; Industrial Computer Systems Design, semester one 2010, as well as Alan Punch’s 2009 thesis, Implementation of Advance Control Technology in the Murdoch University Pilot Plant.

All research and work previously undertaken for the upgrade has been conducted theoretically with respect to Experion and C300 controller hardware. This is because the C300 controller and Experion software was not previously available for programming at Murdoch University. The previous PLC code was provided to Honeywell with intent of migrating the ladder logic code into Experion’s function block code. Even though the communication mediums had been researched previously including the serial MODBUS link, implementation through Experion adds another level of complexity due to the foreign nature of the software and hardware.

The upgrade is nearing completion, with all hardware and software purchased and at the final stage of installation. Once all hardware is installed the remainder of the upgrade will consist of building the communication medium and base level code from ground up as well as commissioning the entire plant.
1.2 Statement of Project Problem

The Pilot Plant at the beginning of this project was not operational.

The C300 controller and IOM's had been installed in the hardware cabinet. The majority of the I/O wiring had been conducted however not to an acceptable degree as illustrated in Figure 1.

The plant required a complete overhaul. Every wire needed to be accounted for prior to supplying power to any of the plant equipment.

The Experion PPServer1 had been installed and configured to the Pilot Plant server computer. However, as discussed later in this report, the server did need minor configuration changes.

![Figure 1: State of Wiring at beginning of Thesis](image)

1.2.1 Issues requiring solutions for completion of project

The nature of this project required a large degree of research. This is because the technologies that have been implemented are recent developments in the industry with minimal knowledge of prior operating and configuration procedures. Due to the lack of available resources pertaining to the implementation of Experion PKS, a number of
obstacles needed to be overcome that were fundamental to the success of the project. These obstacles are listed below with solutions presented throughout this report. These issues are highlighted because each required individual research to understand how they work prior to resolving their issues within the Pilot Plant.

- Experion PKS Fault Tolerant Ethernet (FTE) network requires configuring.
- C300 to IOM, IOLink requires configuring as well as identification of all IOMs to the C300.
- Configuring the analog input and output ranges is required from the CPUs perspective.
- Honeywell’s Experion PKS software was considered as a foreign program. This is because no one at Murdoch University was familiar with implementing, configuring or simply navigating through the software, thus the implementation of all software issues is considered a major project issue and requires a large degree of research. Related Experion software issues include:
  - Function Block (FB) coding within the Control Execution Environment (CEE)
  - Control Module (CM) assignment and understanding the relationship between CMs, Points and Parameters.
  - Configuration of the required internal control algorithms available via the pre configured PID FBs.
  - Discovering how to interface process variables from FB code to the MODBUS TCP channel (solution became PCDI discussed later)
- Configuration of a direct MODBUS SCADA channel that communicates direct to the VFDs without the need for the C300. This was constructed from a safety and diagnostic prospective.

- Configuration of the MODBUS TCP to serial MODBUS RTU Bridge device.

- Configuration of the Danfoss FC102 VFDs for communicating over a serial MODBUS RTU link.

- Wiring and cabinet diagrams required updating.

- Commissioning every instrument in confirming communication to the C300 once the FTE, IOLinks and MODBUS channel are all operational.

- Implementing FB code for all plant interlocks.

- Assigning sensible and unique names to every point that requires reading/writing to from Excel.

- Construction of the Station HMI user display screens.

- Configuration of Microsoft Excel Data Exchange protocol on both the server and client computers.

- Testing Excel communication and construction of a default Excel PID Controller.

- Development of student user guides for operating the plant through either Station or Excel.

- Development of a number of Standard Operating Procedures (SOPs) so that future students have a point of reference for future Experion based projects.
1.3 Objective

The goal for this project is to have the Pilot Plant completely operational and ready for use as a teaching tool for undergraduate electrical engineering students majoring in Instrumentation and Control or Industrial Computer Systems Engineering.

This will require both a hardware and software upgrade. The hardware upgrade will incorporate the installation and configuration of Honeywell’s C300 Controller and associated I/O modules as well as the previously installed Danfoss Variable Speed Drives (VSD’s) over a serial MODBUS link.

The software will be upgraded to Honeywell’s Experion PKS and will include a freshly designed Human Machine Interface (HMI).

Excel will be used for the software environment in which students will be able to implement unique control solutions. Excel must be able to read both current and historical data so that advance control schemes such as Dynamic Matrix, Supervisory and Fuzzy Logic Control algorithms can be implemented. The server must also be able to read data direct from Excel in order to give students control over manipulated variables.

The bottom level code that executes in the C300 will require safety programming to ensure that the plant is operated on two levels of safety. Firstly, the plant must be operated with minimal harm to humans, thus unique safety interlocks need programming. Secondly, the plant must be operated with minimal harm to equipment, therefore equipment interlocks will be required on every VFD to prevent cavitation of the pumps. These interlocks are implemented on the bottom level code so that they are active for both Station and Excel plant operation.

To completely equip students for implementing the best control schemes, piping and instrumentation diagrams (P&IDs) with names that relate to data sheets and tag names are required. Thus students can study the P&IDs, apply Lee, Newell, & Cameron’s
(1998) Total Plant Control Guidelines, select what they believe to be the best control loops and easily read/write to desired points.

Future students will have access to User Guides that provide all requirements for operating the Plant via either Station or Excel.

Additionally the Pilot Plant website will be updated to provide a second reference for students seeking advice on Pilot Plant related issues.

Finally, due to potential future projects that relate to Experion and the Pilot Plant, a number of Standard Operating Procedures (SOPs) and Functional Description (FDs) documents will be constructed throughout the duration of this project. These documents provide future students a starting point for understanding the functionality of the Pilot Plant.

All objectives for this project are fuelled by a time deadline. This time deadline is due to the move of the Pilot Plant to the new Engineering and Science building at Murdoch University South Street campus. The deadline adds another level of complexity to the project in that all above objectives must be met before 1 November 2010. To aid in the move of the plant, an additional moving pack (Appendix PP-5001) was constructed to provide commissioning procedures for starting up the plant after the move.

1.4 Project Design

1.4.1 Project Architecture

As stated previously, the goal for this project is to have the Pilot Plant completely operational and ready for use as a teaching tool for undergraduate electrical engineering students. Additionally the Plant must be completely operational prior to the move into the new Engineering and Science building.

To achieve this all of the project problems listed need to be resolved and the objectives met prior to 1 November 2010.
These objectives are illustrated in the project architecture of Figure 2.

Figure 2: Project Architecture

The objectives have been considered with regard to the level of competency of students.

The operation and control of the Pilot Plant can be demonstrated via Station. One with little or no knowledge of the Pilot Plant will be able to physically monitor levels, flows and temperatures, and relate each to values on the HMI.

Novice students with limited knowledge of instrumentation or control can operate the plant under the pre-configured PID control loops. The ability to change the controller parameters for gain, reset rate and derivative will be located on the HMI. Conversely the ability for front panel manual control will also be available via the HMI.

Advanced students will have the ability to study the Pilot Plant P&ID's, select what they think to be the best solutions for control loops, and implement their control schemes through Excel.

Data sent from client computers to field instruments passes through the C300, thus within the Control Execution Environment of the C300 all safety interlocks must be constructed.
1.5 Achieving Objectives

As illustrated in Figure 3, the format of this project requires a number of sequential stages. These stages correspond directly to the construction of the project architecture presented in Figure 2 and present a logical solution to achieving the objectives.

The first stage of the project consisted of a hardware installation. This stage constructs the foundation for the remainder of the project and consisted of installing:

- C300, Firewalls and IO Modules.
- Wiring of all digital and analog instruments to the IO Modules.
- Design cabinet layout for relays.
- Lantronix Dr Xpress MODBUS TCP Bridge.
- RS485 MODBUS link to VFDs.
- Fault Tolerant Ethernet network.
- Disconnecting the Ball Mill VFD and re wiring the Ball Mill motor to be digitally controlled.

After the hardware is installed, the process of commissioning can begin. This stage consists of commissioning:

- C300 and IO Modules.
- Every digital and analog signal in the plant.
- Lantronix Bridge Converter.
- Danfoss FC102 drives for MODBUS RTU communication.
- Establishing communication to VFDs through two different paths:
  - SCADA Points; and
- **PCDI Points.**

Once this stage is complete all instruments in the plant can be read or written to from Control Builder. Thus the user interface can be constructed as well as all bottom level interlocks. This stage marks the beginning of the software side of the project.

Included in the software development is the configuration of Microsoft Excel Data Exchange (MSEDE) communication. MSEDE requires configuring on both the server and client computers and results in the ability to read current and historical data and write to process variables.

An ongoing process throughout the progression of each stage is the development of documents for future reference. These documents have all been uploaded to the Pilot Plant web page and a number of them are included throughout the appendices.

![Figure 3: Stages of completion](image-url)

The remaining chapters of this report are structured to give an indication of the work undertaken in completing each stage.

Chapter Two: Technical Reviews examines the Experion PKS software suite and the MODBUS protocol. The chapter establishes the technical lingo that the forthcoming chapters contains. Chapters Three to Seven discuss issues associated with each project stage and Chapter Eight overviews the future of the Pilot Plant.
CHAPTER TWO: Technical Reviews

The terminology used in the remainder of this report may appear confusing without knowledge of the Experion software layout or the MODBUS protocol. Prior to further discussion on the Pilot Plant upgrade, the Experion C300 controller, Experion software and MODBUS protocol will be examined.

2.1 Review - C300 Controller & Control Execution Environment

The C300 controller implemented into the Pilot Plant is the latest Honeywell controller available. It is considered a hybrid control system that takes advantage of both Distributed Control System (DCS) and SCADA topologies. As a result, the C300 offers the benefits of real time control processing between peer to peer devices as well as a potential master slave hierarchy between components from multiple manufacturers (Bailey & Wright, 2003). One of the benefits of using a Honeywell C300 and Experion PKS in the Pilot Plant is that the software for configuring the server, developing the control strategies, coding the C300 and developing dynamic user display screens is all part of the Experion PKS software package. Part of this software package is the Control Execution Environment (CEE) core software (Control Builder) which is discussed in section 2.2 of this report.

The CEE provides a control execution and scheduling environment that is far more advanced than that of the previous Allen Bradley PLC5. The CEE is capable of operating control strategies that integrate SCADA point communication such as the Peer Control Data Interface (PCDI) functionality (discussed in section 4.6) and points read directly from analog and digital IOMs. Another difference between the C300 and the PLC5 is the use of Function Block (FB) code rather than ladder logic. FB code provides a more visual approach to implementing control strategies and support logic programming, continuous and sequential control as well as model based control. Thus in itself provides an opportunity for implementation of advance control schemes through FB code within the CEE.
Each FB contains a number of predefined features including alarm settings, control algorithm selection as well as maintenance statistics which the user has the ability to control in either the CEE or in real time via Station software. FBs are combined and interconnected via soft wiring in either Sequential Control Modules (SCMs) or Control Modules (CMs). SCMs provide another level of graphical programming and have not been used for the programming of the Pilot Plant. CMs however provide the platform that all Pilot Plant interlocks are coded through.

CMs are assigned to a CEE and automatically become points within the CEE. Every FB within the CM becomes a parameter of the CM point. Thus every piece of information within a CM can be accessed via its "Point.Parameter" identification scheme and used throughout the Experion system. This includes use in other control strategies or for operator purposes. With respect to the Pilot Plant, the point and parameters provided for Excel communication correspond to this principle. Thus the user does not need to understand where the information is coming from nor where writing to, but instead receives a uniquely defined Point and Parameter name that the user can identify as either a PV, OP or SP. This provides the framework for ground level interlock programming in that all PVs written to the plant must pass a logical sequence of FBs prior to being sent to plant equipment.

This is discussed further in Appendix PP-4003 and illustrated in the Pilot Plant Excel point parameter names of Appendix PP-1001.

The C300 CEE supports an execution period ranging from 50 milliseconds to 2000 milliseconds and does not depend on the number of CMs loaded. One benefit of the CM architecture is that users can deactivate selected CMs while the remainder of CEE continues to execute. With the same respect new CMs can be constructed and loaded to the C300 without the hassle of deactivating existing CMs. The user also receives full control over both FB execution orders within each CM and CM execution orders within
the CEE. This is very important with FB coding when a sequential execution of FBs is required.

2.2 Review - Experion software

The Experion PKS software suite is an engineering tool used for configuring hybrid DCS / SCADA topologies. In doing so the software package allows server configuration, user display creation and control strategy development applications all in an integrated environment. Experion PKS provides a unique configuration environment for every aspect of the hybrid topology. The environments used in constructing the Pilot Plant include the overall management environment: Configuration Studio, Control Builder, Quick Builder and HMIWeb Display Builder. As each environment is significant in its own right, each will be considered.

2.2.1 Configuration Studio

The role of Configuration Studio is to provide a central location from which the Experion system is configured. The different software tools required to configure parts of the system are launched from Configuration Studio. Configuration Studio provides a central environment in which the user can navigate to all other Experion configuration environments. With respect to the Pilot Plant, Configuration Studio is currently only linked to one server, which is PPServer1. Therefore as illustrated in the Pilot Plant architecture of Figure 2, all plant data, regardless of being part of the DCS or SCADA links must pass through PPServer1. It is due to this that Experion PKS is able to offer a hybrid system with seamless integration between different devices. The initial Configuration Studio screen is illustrated in Figure 4. The extensive list of applications which are linked to PPServer1 shows that Configuration Studio provides a path for configuring all things related to the Experion PKS suite including, security access, historical data logging and trend configuration. All of which have Standard Operating Procedure (SOP) documents available in Appendix PP-3000. Additionally,
Configuration Studio provides a path for launching Control Builder, Quick Builder and HMI Display builder.

![Configuration Studio](image)

**Figure 4: Configuration Studio**

### 2.2.2 Control Builder

As mentioned in the CEE review, Control Builder is the environment where control strategies are developed and loaded to the CEE of the C300. Control Builder is a graphical tool for building control strategies and takes traditional ladder logic programming to a new level. This is because the object-oriented, graphical approach to coding control strategies dramatically reduces the effort required to design, implement and document control applications. Additionally, the final block diagram – control strategy also offers a potential HMI display screen for online monitoring and control. This is illustrated in Figure 5. Also highlighted in Figure 5 are the Project, Monitoring and Library tabs.

The project tab contains a tree for each Central Processing Module CPM. The Pilot Plant only has one C300 and therefore only one CPM which is defined as CPM_1.
Within CPM_1 is the CEE which currently supports all the CMs that contain the FB code for the Pilot Plant. At the same level as the CEE is the IOLINK. The IOLINK contains all the IOMs (2 digital input, 2 digital output, 2 analog inputs and 1 analog output) modules.

The monitoring tab is a reflection of the projects tab and differs in that it offers online monitoring of FBs.

The library tab contains an extensive portfolio of FBs. When developing control strategies the library tab is used to drag and drop FBs into CMs. A number of FBs are considered in this report including the unique PCDI blocks used for MODBUS communication.

2.2.3 Quick Builder

The Quick Builder software has a number of vital purposes. These include configuring both Servers and Stations. Additionally Quick Builder is used for linking SCADA data to...
the server. The SCADA points in the Pilot Plant are all associated with the MODBUS link for each VFD. Thus a SCADA point for the Pilot Plant refers to data locations (register locations) within a VFD. The Pilot Plant only requires one SCADA channel, which is the MODBUS TCP channel. Quick Builder allows the construction of controllers and points that are directly associated with SCADA channels.

An SOP document is included in Appendix PP-3009, which illustrates step by step the configuration of a MODBUS TCP channel, associating a controller to the channel and targeting specific points within the controller.

![Figure 6: Quick Builder](image)

### 2.2.4 HMIWeb Display Builder

The HMIWeb Display Builder environment is used to construct operator screens and link them to the Experion system. It is a specialised drawing application that enables the user to create custom displays for Station. Complex plant information can be presented in a sophisticated and user-friendly manner that makes it easier for operators to interpret. The software comes equipped for implementation of Abnormal Situation Management (ASM) standards for operator displays, which is discussed in Chapter Six.
The architecture of HMIWeb Display Builder is illustrated in Figure 7.

![Figure 7: HMIWeb Display Builder](image)

### 2.3 Review – MODBUS Protocol

#### 2.3.1 OSI reference model

The International Organization for Standardization (IOS) constructed the OSI reference model for communication between open systems in 1978. The model has since become known as the Open System Interconnection Reference model or in more general terms, the OSI model. This model is essentially a data communications management structure that breaks data communications down into a manageable seven layer hierarchy (Reynders, Mackay, Wright, & Mackay, 2004) as illustrated in Figure 8.
Each layer’s purpose is independent of the other layers. However each layer interfaces with the layers above and below. This provides a framework for developing protocols for each layer independently of other layers and thus the framework to communicate with any other compliant system.

The model operates via passing data and control information down through the seven layers. At each layer of the model, Protocol Data Units (PDU) are wrapped around the received package. Each layer’s PDU can be considered as headers, trailers or both depending on the applied protocol. At the physical layer, the data is transmitted over a physical medium. The receiver sends the entire data package through the reverse order, stripping away each layers PDUs until the initial data can be read at the application layer (Reynders, Mackay, Wright, & Mackay, 2004).

2.3.2 MODBUS Protocol

The MODBUS protocol fits into the OSI model as part of the Application layer 7. The protocol provides client/server communication between different devices connected to different types of networks. With respect to the Pilot Plant, this provides the solution to
communicating to the VFDs over an RS485 / FTE medium with use of a bridge device to strip/apply the PDUs that are associated with TCP transmission.

The MODBUS protocol implements a master/slave architecture that takes on the traditional ‘request/ response’ standard with four base messages types:

- **MODBUS Request**: Client sends the message on the network to initiate a transaction
- **MODBUS Response**: Server sends this message in response to Client
- **MODBUS Confirmation**: Client acknowledges the received message
- **MODBUS Indication**: Server confirms request message.

The defining packets of the MODBUS protocol are the Address packet, Function Code Packet, Data packets and Error check packet which are illustrated in Figure 9. The address packet is only a single byte of data and is different for request and response frames. In request frames, the address packet houses the Remote Terminal Units (RTUs) address on the MODBUS link. In a response frame the address packet houses the address of the responding device. For the Pilot Plant this corresponds to a unique MODBUS RTU address for each VFD (These addresses are illustrated in Table 1). The MODBUS protocol allows for address fields between 1 and 247.

The Function Code packet contain a function code that defines the action expected for the target controller, this field also consists of only a singly byte.

The Data packets contain the substance of the message and differs in length depending on the function code specified. These packets define what the controller is to do. With respect to a request from Experion to the Danfos FC102 VFDs in the Pilot Plant, this field contains information that the drive may need to complete the request function. In a response from the VFDs, this field contains any data requested. The VFD
Overview Display page in station demonstrates the use of MODBUS. All data points on the display page are read over the MODBUS channel. This display page is illustrated in Figure 27.

The Error Check consists of two bytes and performs a traditional Cyclic Redundancy Check (CRC) sum on the message frame. This provides confirmation of successful message transmission.

![Figure 9: Generic MODBUS Frame](image)

(Reynders, Mackay, Wright, & Mackay, 2004)

One reason why MODBUS has received much success in industry is because the protocol can be implemented over a number of different physical mediums (layer 1 of OSI model). Popular mediums include transmitting the data in serial format over RS-232 or RS-485 links or encapsulating the MODBUS PDU so it can be transported as a packet of data by TCP/IP over an Ethernet or Internet network. The architecture of the Pilot Plant takes advantage of MODBUS TCP in communicating the data over Honeywell’s FTE network and serial MODBUS RTU over RS-485 in communicating serially to each VFD. This is illustrated in the Pilot Plant architecture of Figure 2.

RS-485 is a two-wire communication standard where both line drivers and receivers are connected to the same pair of shielded, twisted wires. Thus RS-485 takes the traditional nature of a two wire bus and adopts a multi-drop wiring configuration as illustrated in Figure 10. Termination resistors of 120 Ohms are required at either end of the bus link. The Danfoss FC102 VFDs in the Pilot Plant each have 120 Ohm termination resistors internally which require activating via a front panel switch. This is
active for the FP VSD. A second 120 Ohm terminator is located on the Lantronix DR XPress bridge device. The RS-485 Earthing line in the Pilot Plant is also internally connected to the earth of each VFD which is intern earthed to the housing cabinet.

Figure 10: RS - 485 cabling for serial MODBUS RTU

(Reynders, Mackay, Wright, & Mackay, 2004)

When the Experion server packages the MODBUS protocol for transmission, its OSI model packages the message for TCP/IP transmission. Thus the message takes on a standard TCP/IP structure requiring a destination IP address and port number. Experion uses Port No 502 for all MODBUS communications. The MODBUS bridge devices IP address in the Pilot Plant is 134.115.133.172. Configuring this address is discussed in Chapter Four, section 4.3. A step-by-step guide for configuring the Lantronix DR Xpress Bridge device is provided in Appendix PP-3010. The final TCP packet is illustrated in Figure 11.
This packet is sent to the Lantronix DR XPRESS bridge converter from the Experion server. The bridge operates by extracting the MODBUS frame from the TCP frame. The extracted MODBUS frame is then transmitted over a RS-485 multi drop link with every VFD connected. Conversely a return signal from a VFD is received by the Lantronix bridge device via the RS-485 link, the package is then sent through the bridge devices OSI model and essentially packaged for TCP transmission. The final MODBUS TCP frame is then transmitted over the FTE network to the Experion server.
CHAPTER THREE: Hardware Installation

The first stage of the project consisted of a hardware installation. This stage constructs the foundation for the remainder of the project and consisted of installing:

- C300, Firewalls and IO Modules.
- Wiring of all digital and analog instruments to the IO Modules.
- Design cabinet layout for relays.
- Lantronix Dr Xpress MODBUS TCP Bridge.
- RS485 MODBUS link to VFDs.
- Fault Tolerant Ethernet network.
-Disconnecting the Ball Mill VFD and re wiring the Ball Mill motor to be digitally controlled.

3.1 Work Conducted

Extensive work was conducted in identifying all relays and ordering them in a constructive fashion. This was needed as the I/O inputs to each IOM were not in a sequential order. Figure 12 illustrates the new configuration of the relays.

Additionally all 3WV’s in the field had to be re-wired, so to receive 24 VAC. Previously the valves were receiving a 240 V signal which is not safe nor practical in a teaching facility.
Piping and Instrumentation Diagrams for the entire plant were constructed during this phase. The diagrams are unique in that each instrument tag name corresponds to its associated tag reference in the server. This provides an easy solution for students to identify the correct points and parameters necessary for Excel communication. Figure 13 is included to highlight the level of complexity that each P&ID entitles. The diagrams were constructed with intent for students use thus do not include piping and instrument size specifications.
Appendix PP-0000 includes the wiring diagrams and P&ID's that were constructed during this stage.
CHAPTER FOUR: Commissioning

Stage two consisted of commissioning and configuring all I/O to the C300 as well as the SCADA points through the MODBUS channel.

As listed previously this includes:

- Commissioning C300 and IO Modules
- Configuring analog ranges
- Configuring the Danfoss FC102 drives for MODBUS RTU communication
- Configuring the Lantronix Bridge Converter for MODBUS RTU via RS 485
- Establishing communication to VFDs
  - Through a SCADA channel
  - Through a PCDI channel

Each of these points is discussed in this chapter.

4.1 Commissioning – C300

A number of issues became apparent upon trouble shooting the communication to the C300 and associated IOMs. One major communication error was identifying each IOM. This is because each I/O Module associated with the C300 requires a unique address. Honeywell have adopted an external pin addressing system that requires each IOM to be identified both in the software and on the physical unit located on the Input Output Termination Assembly (IOTA). Initially the software addresses were different to the physical addresses. Matching of these addresses is illustrated in Figure 14. The number of IOMs associated to a C300 controller can range from 1 to 40.
Figure 14: Configuring IOM number.

Additionally within the configuration tab of each analog IOM channel, configuration of analog input and ranges is achieved. Each analog input channel must be configured individually. For example, the analog input ranges for tank levels range between 0 and 100% where 0% indicates zero potential difference between the liquid inside a tank and the ambient atmosphere pressure and 100% indicates the vessel is full. The percentage range is also directly related to the voltage and current seen at the input to the channel, thus 1 V / 4ma = 0% and 5V / 20ma = 100%.

The process of configuring I/O through Control Builder is contained in Appendix PP-3004.

Another major issue was the communication link between the Experion server and the C300 controller. The connection between the C300 controller and the Experion server is achieved via Honeywell’s double link, Fault Tolerant Ethernet (FTE). This Ethernet network is Honeywell’s proprietary technology and often referred to as the FTE network. An FTE network is designed to tolerate multiple concurrent faults on either
link. Each link is colour coded so as to distinguish the networks and are referred to as either the ‘yellow’, ‘network A’ or the ‘green’, ‘network B’ respectively (Honeywell, 2008c). Network A and network B both leave the C300 controller and run to separate firewalls, thus providing an additional level of security. Networks A and B then follow a path consisting of multiple switches creating a small FTE network between the C300 and the Experion Server. This is illustrated in Figure 15.

Due to the migration of the plant into the new building, the double layer FTE network was not implemented during this project. Instead a single switch was implemented with both networks struggling to communicate. This resulted in an increase in the number of network faults and ultimately resulted in the server communication failing approximately two to three times a minute. This was temporarily fixed by removing one of the FTE links as well as its associated firewall from the network. The complete double link FTE network will be implemented upon relocation of the plant into the new Engineering and Science building.
4.2 Configuring VFD’s

Part of the Pilot Plant’s hardware upgrade included replacing all the VFDs with Danfoss FC102 VFDs communicating over a serial MODBUS link. The MODBUS link is used to demonstrate the versatility of Experion PKS in interfacing with a range of communication mediums and protocols.

For the MODBUS channel to work, three devices require configuring. The server needs to know if the data is intended for MODBUS TCP in order to package the data as illustrated in Figure 11 and export to the Lantronix bridge converter. The Lantronix bridge converter needs to know if it is to send the data over RS-232 or RS-485 serial link and finally each Danfoss VFD needs to be configured to be a Remote Terminal Unit (RTU) on the MODBUS link (Danfoss, 2009).

Each drive is required to be individually checked and set up for serial MODBUS RTU communication. This can be achieved through the front panel as well as through Danfoss MCT10 software as illustrated in Figure 16 (a) and (b). The software allows configuring both communication and operating conditions. Within the "Comm. And Options" page of each drive, a unique RTU address is selected, the MODBUS baud rate is chosen (9600) and a number of serial response time-outs are selected. Within the Limits/Warning page, a number of operating conditions were selected including a minimum and maximum operating frequency of 10 Hz and 50 Hz respectively.

To aid in the move of the Pilot Plant, additional documentation on configuring the drives for MODBUS is included in the moving pack of Appendix PP-5000 as well as an SOP document in case the drives require re-configuring after the move.
It should be noted that the drive addresses have been configured to be the same as what Alan Punch used in his 2009 thesis work. This has been done so that the MODBUS TCP Labview program that Punch constructed can be used if required to aid in re-conducting the plant after the move. The drive addresses are given in Table 1.
Table 1: VFD MODBUS Parameters (Punch, 2009)

<table>
<thead>
<tr>
<th>#</th>
<th>Drive Name</th>
<th>MODBUS Address</th>
<th>Baud</th>
<th>Parity</th>
<th>Stop Bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ball Mill Pump</td>
<td>141</td>
<td>2</td>
<td>9600</td>
<td>Even 1</td>
</tr>
<tr>
<td>2</td>
<td>Ball Mill Drive</td>
<td>201</td>
<td>3</td>
<td>9600</td>
<td>Even 1</td>
</tr>
<tr>
<td>3</td>
<td>Cyclone Feed Pump</td>
<td>241</td>
<td>4</td>
<td>9600</td>
<td>Even 1</td>
</tr>
<tr>
<td>4</td>
<td>Cyclone Recycle Pump</td>
<td>341</td>
<td>5</td>
<td>9600</td>
<td>Even 1</td>
</tr>
<tr>
<td>5</td>
<td>Cyclone Underflow Pump</td>
<td>381</td>
<td>6</td>
<td>9600</td>
<td>Even 1</td>
</tr>
<tr>
<td>6</td>
<td>Lamella Underflow Pump</td>
<td>421</td>
<td>7</td>
<td>9600</td>
<td>Even 1</td>
</tr>
<tr>
<td>7</td>
<td>Flow Disturbance Pump</td>
<td>521</td>
<td>8</td>
<td>9600</td>
<td>Even 1</td>
</tr>
<tr>
<td>8</td>
<td>Needle Underflow Pump</td>
<td>561</td>
<td>9</td>
<td>9600</td>
<td>Even 1</td>
</tr>
<tr>
<td>9</td>
<td>Dye Pump</td>
<td>611</td>
<td>10</td>
<td>9600</td>
<td>Even 1</td>
</tr>
<tr>
<td>10</td>
<td>Product Pump</td>
<td>681</td>
<td>11</td>
<td>9600</td>
<td>Even 1</td>
</tr>
</tbody>
</table>

4.3 Configuring Lantronix Bridge converter

The Lantronix converter is configured through DeviceInstaller software which can be downloaded free from their website. The latest version of the software (DeviceInstaller 4.3.0.0) was downloaded and used to configure the device. It is recommended that this software is used in the future as no firmware upgrade is required. When configuring the device for MODBUS/TCP communication, the following settings are required:

**MODBUS/TCP to RTU Bridge Setup**

1) Network/IP Settings:

- IP Address: 134.115.133.172
- Default Gateway: 134.115.133.1
- Netmask: 255.255.248.0

2) Serial & Mode Settings:

- Protocol: MODBUS/RTU,Slave(s) attached
• Serial Interface: 9600,8,E,1,RS485

3) Modem Control Settings:

• Modem control not available with RS422/RS485

4) Advanced MODBUS Protocol settings:

• Slave Addr/Unit Id Source: MODBUS/TCP header
• MODBUS Serial Broadcasts: Disabled (Id=0 auto-mapped to 1)
• MB/TCP Exception Codes: No (no response if timeout or no slave)
• Char, Message Timeout: 00050msec, 00500msec
• Serial TX Delay: 0050msec

The DeviceInstaller software is attached to the electronic Appendix PP-2006 and includes an SOP for communication via a cross-over cable or over the Murdoch network.

It was established that the Lantronix converter could be communicated to through one of the C300’s firewalls. This hides the device from the Murdoch Network and reduces security risks. With this configuration it is not necessary to withhold the device’s IP address as it is not seen from the Murdoch network. This is illustrated in the project architecture of Figure 2. Also illustrated in Figure 2 are the multiple communication paths through the fire wall to the bridge converter. These two paths illustrate MODBUS TCP communication direct from the server and MODBUS TCP communication from the C300 controller. The uniqueness of these two paths is in how they are configured for communication. The various ways of configuring MODBUS channels are discussed next.
4.4 Establishing communication to VFD's

The direct channel from the server to the bridge is configured as a SCADA channel through the Quick Builder software. These points are provided for diagnostic purposes because the channel remains active even if the C300 controller fails. Thus all the points located on the Station VFD overview page, Figure 27 are reading raw data directly over the MODBUS channel from the VFDs.

The Second MODBUS TCP channel is a Peer Control Data Interface (PCDI) channel, which provides a means of interfacing the CEE FB code with the VFDs. To construct a PCDI channel, a PCDI software license is required where as no additional license is required to construct points via Quick Builder (Honeywell, 2008b).

When constructing these two channels a number of technical issues needed resolving. These are considered next.

4.5 Configuring Drive Control through Quick Builder

An SOP for configuring SCADA points is included in Appendix PP-3009. This SOP will be very useful if additional SCADA points are added to the Pilot Plant. Building SCADA points requires setting a Channel, Controller/s and desired Points (Honeywell, 2003).

This SOP outlines the configuration of all three elements and highlights the issues associated with address range limitations. Table 2 illustrates the SCADA Points that are associated with the Danfoss VFDs.
### Table 2: SCADA Points in Pilot Plant

<table>
<thead>
<tr>
<th>Item Name</th>
<th>Description</th>
<th>Associated Controller</th>
<th>Controller Offset</th>
<th>OP REGISTER</th>
<th>PV REGISTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODE 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FP_ON_OFF</td>
<td>FEED PUMP 141 - ON / OFF</td>
<td>CONMOD201</td>
<td>-</td>
<td>7 C16</td>
<td>44 C 16</td>
</tr>
<tr>
<td>FP_REF_141_QDB</td>
<td>FEED PUMP 141 VFD - SPEED REFERENCE</td>
<td>CONMOD202</td>
<td>-15535</td>
<td>10 C16</td>
<td>-</td>
</tr>
<tr>
<td>FP_VFD_TEMP</td>
<td>FP VFD TEMPERATURE</td>
<td>CONMOD1</td>
<td>-</td>
<td>-</td>
<td>16340 C16</td>
</tr>
<tr>
<td>NODE 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REMPVED (WAS NODE FOR BM)</td>
<td></td>
<td>CONMOD2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NODE 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMP_ON_OFF</td>
<td>BALL MILL PUMP 241 - ON / OFF</td>
<td>CONMOD203</td>
<td>-</td>
<td>7 C16</td>
<td>44 C 16</td>
</tr>
<tr>
<td>BMP_REF_241_QDB</td>
<td>BALL MILL PUMP 241 VFD - SPEED REFERENCE</td>
<td>CONMOD204</td>
<td>-15535</td>
<td>10 C16</td>
<td>-</td>
</tr>
<tr>
<td>BMP_VFD_TEMP</td>
<td>BMP VFD TEMPERATURE</td>
<td>CONMOD3</td>
<td>-</td>
<td>-</td>
<td>16340 C16</td>
</tr>
<tr>
<td>NODE 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRP_ON_OFF</td>
<td>CYCLONE RECYCLE PUMP 341 - ON / OFF</td>
<td>CONMOD205</td>
<td>-</td>
<td>7 C16</td>
<td>44 C 16</td>
</tr>
<tr>
<td>CRP_REF_341_QDB</td>
<td>CYCLONE RECYCLE PUMP 341 VFD - SPEED REFERENCE</td>
<td>CONMOD206</td>
<td>-15535</td>
<td>10 C16</td>
<td>-</td>
</tr>
<tr>
<td>CRP_VFD_TEMP</td>
<td>CUP VFD TEMPERATURE</td>
<td>CONMOD4</td>
<td>-</td>
<td>-</td>
<td>16340 C16</td>
</tr>
<tr>
<td>NODE 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUP_ON_OFF</td>
<td>CYCLONE UNDERFLOW PUMP 361 - ON / OFF</td>
<td>CONMOD207</td>
<td>-</td>
<td>7 C16</td>
<td>44 C 16</td>
</tr>
<tr>
<td>CUP_REF_361_QDB</td>
<td>CYCLONE UNDERFLOW PUMP 361 VFD - SPEED REFERENCE</td>
<td>CONMOD208</td>
<td>-15535</td>
<td>10 C16</td>
<td>-</td>
</tr>
<tr>
<td>CUP_361_VSD_TEMP</td>
<td>CUP VFD TEMPERATURE</td>
<td>CONMOD5</td>
<td>-</td>
<td>-</td>
<td>16340 C16</td>
</tr>
<tr>
<td>NODE 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LUP_ON_OFF</td>
<td>LAMELLA U/F PUMP 421 - ON / OFF</td>
<td>CONMOD209</td>
<td>-</td>
<td>7 C16</td>
<td>44 C 16</td>
</tr>
<tr>
<td>LUP_REF_QDB</td>
<td>LAMELLA U/F PUMP 421 VFD - SPEED REFERENCE</td>
<td>CONMOD210</td>
<td>-15535</td>
<td>10 C16</td>
<td>-</td>
</tr>
<tr>
<td>LUP_421_VSD_TEMP</td>
<td>LUP VFD TEMPERATURE</td>
<td>CONMOD6</td>
<td>-</td>
<td>-</td>
<td>16340 C16</td>
</tr>
<tr>
<td>NODE 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FDP_ON_OFF</td>
<td>FLOW DISTURBANCE PUMP 521 - ON / OFF</td>
<td>CONMOD211</td>
<td>7 C16</td>
<td>44 C 16</td>
<td></td>
</tr>
<tr>
<td>FDP_REF_521_QDB</td>
<td>FLOW DISTURBANCE PUMP 521 VFD - SPEED REFERANCE</td>
<td>CONMOD212</td>
<td>-15535</td>
<td>10 C16</td>
<td>-</td>
</tr>
<tr>
<td>FDP_521_VFD_TEMP</td>
<td>FDP VFD TEMP</td>
<td>CONMOD7</td>
<td>-</td>
<td>-</td>
<td>16340 C16</td>
</tr>
<tr>
<td>NODE 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NTP_ON_OFF</td>
<td>NEEDLE TANK U/F PUMP 561 - ON / OFF</td>
<td>CONMOD213</td>
<td>-</td>
<td>7 C16</td>
<td>44 C 16</td>
</tr>
<tr>
<td>NTP_REF_561_QDB</td>
<td>NEEDLE TANK U/F PUMP 561 VFD - SPEED REFERENCE</td>
<td>CONMOD214</td>
<td>-15535</td>
<td>10 C16</td>
<td>-</td>
</tr>
<tr>
<td>NTP_561_VFD_TEMP</td>
<td>NTP VFD TEMPERATURE</td>
<td>CONMOD8</td>
<td>-</td>
<td>-</td>
<td>16340 C16</td>
</tr>
<tr>
<td>NODE 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DP_ON_OFF</td>
<td>DYE PUMP 611 - ON / OFF</td>
<td>CONMOD215</td>
<td>-</td>
<td>7 C16</td>
<td>44 C 16</td>
</tr>
<tr>
<td>DP_REF_611_QDB</td>
<td>DYE PUMP 611 VFD - SPEED REFERENCE</td>
<td>CONMOD216</td>
<td>-15535</td>
<td>10 C16</td>
<td>-</td>
</tr>
<tr>
<td>DP_611_VFD_TEMP</td>
<td>DP VFD TEMPERATURE</td>
<td>CONMOD9</td>
<td>-</td>
<td>-</td>
<td>16340 C16</td>
</tr>
<tr>
<td>NODE 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PP_ON_OFF</td>
<td>PRODUCT PUMP 681 - ON / OFF</td>
<td>CONMOD217</td>
<td>-</td>
<td>7 C16</td>
<td>44 C 16</td>
</tr>
<tr>
<td>PP_REF_681_QDB</td>
<td>PRODUCT PUMP VFD 681 - SPEED REFERENCE</td>
<td>CONMOD218</td>
<td>-15535</td>
<td>10 C16</td>
<td>-</td>
</tr>
</tbody>
</table>

### 4.5.1 Addressing SCADA points (range limitations)

One key issue when configuring the points shown in Table 2 was understanding the register range limitations of the Experion server.
The Experion server can only access a maximum of 4096 \( (2^{12}) \) records in a particular file. Therefore if the server needs to access a record beyond this limit then an offset is required within the channel. This is the case for accessing register 50010 in the Danfoss drives (speed reference register).

For Universal MODBUS, an offset must be used to reference addresses outside the range 0x0000 and 0x1FFF. Thus to access addresses between 0x0000 and 0x4000 within the Danfoss drives two controllers are needed (which is the case for turning the drive on register 7 and controlling the drive speed register 50010). One with an OFFSET = 0 for all addresses up to 0x1FFF, and one with OFFSET = 2000 for all addresses between 0x2000 and 0x3FFF (Honeywell, 2003);(Honeywell, 2007b). This is illustrated in Equation 1:

\[
\text{Hardware Address} = 2^{16} + (\text{OFFSET}) + (\text{Register Address})
\]

Equation 1: SCADA Point Addressing Ranges

Applying Equation 1 for the Danfoss VFD speed register address 50010 results in an offset of -15535 and a register address of 10:

\[
50010 = 2^{16} - 15535 + 10
\]

Also worth noting from Table 2 is the unit specified for each OP or PV. The points currently constructed are C16 which are signed 16 bit integers and give a range of -32768 to 32767. Table 3 illustrates a number of data formats. Depending on the desired operation, a particular format may be required over another. For SCADA point address locations using C16 data format and Equation 1 should result in the desired register locations.
Table 3: Data Formats

<table>
<thead>
<tr>
<th>DATA FORMAT</th>
<th>DESCRIPTION</th>
<th>COUNTS</th>
<th>SCALED</th>
</tr>
</thead>
<tbody>
<tr>
<td>C16</td>
<td>16-bit, signed. This is the default format.</td>
<td>-32767 to 32768</td>
<td>No</td>
</tr>
<tr>
<td>IEEEFP</td>
<td>Single-precision floating point. Only applicable to analog points</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>S16B</td>
<td>16-bit, signed</td>
<td>-32767 to 32768</td>
<td>Yes</td>
</tr>
<tr>
<td>U16B</td>
<td>16-bit, unsigned</td>
<td>0 to 65535</td>
<td>Yes</td>
</tr>
</tbody>
</table>

4.5.2 Addressing SCADA points (register location mismatch)

The address locations given in Punch (2009) were given with respect to his Labview program. In one of the sub VI's in the program an additional digit was added to the address location. Thus the addresses supplied by Punch (2009) needed to be incremented by one when configured as a SCADA point in Quick Builder.

Table 4 illustrates the register addresses that Quick Builder requires to achieve functional control of the drives.

Table 4: Danfoss FC102 MODBUS Registers for Quick Builder

<table>
<thead>
<tr>
<th>Register</th>
<th>Action</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>50010</td>
<td>Analog Write</td>
<td>Speed Reference</td>
</tr>
<tr>
<td>16140</td>
<td>Analog Read</td>
<td>Drive Current</td>
</tr>
<tr>
<td>16300</td>
<td>Analog Read</td>
<td>DC Bus Voltage</td>
</tr>
<tr>
<td>16400</td>
<td>Analog Read</td>
<td>Drive Temperature</td>
</tr>
<tr>
<td>7</td>
<td>Digital Write</td>
<td>Start/Stop drive</td>
</tr>
<tr>
<td>12</td>
<td>Digital Write</td>
<td>Relay1 Operation</td>
</tr>
<tr>
<td>13</td>
<td>Digital Write</td>
<td>Relay2 Operation</td>
</tr>
<tr>
<td>33</td>
<td>Digital Read</td>
<td>Control Ready</td>
</tr>
<tr>
<td>44</td>
<td>Digital Read</td>
<td>Drive Running/Drive Stopped</td>
</tr>
</tbody>
</table>
4.6 Configuring Drive Control through PCDI

PCDI is used at the code level of the Pilot Plant. PCDI provides a MODBUS TCP channel that writes FB PV outputs direct to their intended register within the Danfoss FC102 Drives. To configure a PCDI channel first the PCDI license must be installed. The PCDI block is available in the Control Builder FB library even without the license installed. However without the license, the PCDI_Master cannot be assigned to a CEE.

Every PCDI channel must have a Master_PCDI block assigned to the CEE. The Master_PCDI block packages the serial MODBUS RTU data for MODBUS TCP transmission (Honeywell, 2008b). Conceptually the Master_PCDI block sends the PV data through an OSI model that is pre-configured for packaging a MODBUS TCP packet.

The data that the Master_PCDI block receives is from either a PCDIFLAGARRCH, PCDINUMARRCH or PCDITEXTARRCH block. However regardless of where the data comes from, the Master_PCDI packages the data in the same way, which is illustrated in Figure 11. Each block is described in Figure 17, which also illustrates the location of the PCDI blocks within the library tab of Control Builder.
For drive control in the Pilot Plant only PCDINUMARRCH blocks are required. These blocks are configured much the same as the Quick Builder points previously discussed. However the raw register address is required without the need for an offset. With respect to the MODBUS protocol and packet structure of Figure 9, the PCDINUMARRRCH exports the entire packet to the PCDI_MASTER. Therefore when configuring each PCDINUMARRCH block the VFDs RTU address, desired Function Code and speed register address are required.

The way that the PCDI block defines the MODBUS function and register location is via the Starting Element Index Parameter (STARTINDEX), which consequently defines the MODBUS address map. This is similar to the hardware address of Equation 1. The STARTINDEX parameter specifies the MODBUS data type and MODBUS address up to 65535 ($2^{16}$) with the most significant digit representing the MODBUS function. For example the address ranges 2xxxxx, 4xxxxx, 5xxxxx, 7xxxxx, 8xxxxx and 9xxxxx all address the same xxxxx register in the Danfos VFD though are read with different function codes and different data formats. Table 5 summarises the STARTINDEX...
ranges that may be required for future development of the Pilot Plant FB code and apply only to PCDINUMARRCH blocks.

Table 5: Starting Element Index Values (Honeywell, 2008b)

<table>
<thead>
<tr>
<th>STARTINDEX RANGES</th>
<th>MODBUS FUNCTION</th>
<th>DATA RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>300001 – 365535</td>
<td>Read Input registers</td>
<td>-32768 to 32767</td>
</tr>
<tr>
<td>400001 - 465535</td>
<td>Read Holding Registers/Write single register</td>
<td>-32768 to 32768</td>
</tr>
</tbody>
</table>

Consequently for the previous example of addressing the speed register within the Danfoss VFDs, only the raw address of 50010 is required plus an additional digit to specify the data format. This register is the location of the speed reference and is the register where the OP for desired speed is needed to be written to, and is included in the 400001 – 465535 STARTINDEX ranges. This makes the final address register required for the PCDINUMARRCH block equal to 450010.

To completely understand the interconnection between the CEE and the MODBUS TCP channel the PCDI architecture will be examined.

4.6.1 PCDI Architecture

The PCDI_MASTER block serves as the communication bridge between PCDI Array Channel blocks and the Lantronix DR XPress with serial line MODBUS RTUs (VFDs).

The PCDI_MASTER block requires configuring to represent a single (MODBUS TCP) bridge. The PCDI_MASTER block supports up to 64 PCDI Array Request Channel Blocks (Honeywell, 2008b). The Pilot Plant requires only eight. These are to send the drive speed reference to each of the VFDs in the plant.

The Lantronix DR XPress bridge can handle up to 16 serial MODBUS RTU connections. Again the Pilot Plant currently has eight RTU (VFDs).
This architecture with respect to the devices used in the Pilot Plant is illustrated below:

Figure 18: PCDI Architecture

(Honeywell, 2008b)

This concludes stage two. The major achievement of this stage includes complete manual control of the VFD as well as reading/writing all analog and digital data.
CHAPTER FIVE: Coding

Stage 3 marked another milestone for the project. Upon beginning this stage, all hardware and software required for completion of the project was available, installed and communicating. Additionally all plant data was communicating to the C300 controller. Certain aspects of the software were still foreign but enough information was known to begin the ground level coding for the Pilot Plant. Included in the ground level coding are the interlocks for both Station and Excel operation as well as the PID controllers for automatic control via Station. This chapter is structured to give an overview of how plant data is read or written to and from CMs. Following this will be a discussion on the features of some advanced FBs and how these features directly affect the way code is implemented. Finally a discussion is given on the actual interlock and PID control algorithms which have been coded for the Pilot Plant. The various PID algorithms that can be selected via a PID FB are considered and in concluding, will be compared to what is taught at Murdoch University as a ‘traditional PID’ algorithm.

5.1 Reading / writing from CMs

All the IO Modules associated with the C300 in the Pilot Plant are located and configured under the IOLink_01 of the CEE. This is because at the configuration stage of the C300 each IOM was assigned to CEE_01. Consequently each IO Module and related channels are available under the IOLink_01 tree of the CPU_01 in the Project tab of Control Builder. With this configuration an IO Module automatically assigns a FB for each of its channels. Although the FBs are not located within the library tab amongst all the other FBs, they are used and configured exactly the same. It should be noted an IOM channel FB can only be used in CM of an assigned CEE, currently this is not a problem as only one CEE is used in the Pilot Plant. This is illustrated in Figure 19.
Writing serial MODBUS data to a VFD from a CM provides another level of difficulty. As discussed in Chapter Four, a PCDI channel is required. The data type being written (boolean or analog) will affect the PCDI block needed in the CM. For drive control in the Pilot Plant PCDINUMARRCH blocks are used to send the desired drive speed over the MODBUS TCP channel. This is illustrated in Figure 20. Being able to read and write data directly into CMs via PCDI blocks means that the data can be used in all ground level coding. The data can also be manipulated by conventional FB methods which is also illustrated in Figure 20, via the multiplication of BMP_241.PV by 163.8. Thus users can implement a drive operating speed via a percentage ranging from 0 to 100%. Meanwhile the speed written to the drive is scaled by 163.8 which gives the operating speed in the range that the drive requires.
5.2 Operation of PID and advance blocks

(Program verses Operator modes)

The library tab within Control Builder has an extensive list of FBs. Amongst the basic logics and mathematic blocks are a number of advanced blocks that have more than one function. The PID function block is one type of advanced block that can be operated in either program mode or operator mode. The difference in modes is directly related to how the block is coded in a CM.

In program mode the functions of the block are completely controlled via individual inputs that are ‘wired’ into the FB. This is illustrated in Figure 21, with external inputs for SP, PV, OP, Manual/Auto control and direct/reverse acting control. The block is pre-configured so that when in program mode it can apply its PID equation to the wired inputs and produce a single OP output. In this mode the digital input for Manual/Auto control will allow the algorithm to be disengaged and the OP being read in is simply written straight out.

The alternative mode of operation is the operator mode. This mode disregards all wired inputs and requires internal connections for PV, SP and OP. At this stage, this mode of
operation has been left alone as it is assumed that this is how advance control strategies such as those associated with Profit Suite are integrated into the system.

Figure 21: PID FB code

5.3 Interlock coding for program mode

All ground level interlocks in the Pilot Plant are logically constructed sequences that provide a path for disengaging plant equipment given the event of abnormal plant operation. An example of how the logic sequence is implemented for the Pilot Plant is given in Figure 22. This example illustrates the interlocks for the Needle Tank Pump (NTP). In the example NTP_RUN_561 digital input channel is true given that the VFD for NTP_561 is on. Thus if the pump is running and either the level in the needle tank drops below 5% or both FT_569 and FT_573 indicate a flow less than 1%, then the VFD will be forced off after 5 seconds. The logical interlock is reset after the pump is disengaged which allows the pump to be turned on after the abnormal situation is fixed. This is achieved in the FB logic code by the digital input channel block NTP_RUN_561 being switched off when the VFD is forced off.

This provides the interlock programming so that the pump never runs dry and the pump is disengaged in the event of a blocked output line. Similar interlocks have been
programmed for all plant pumps and agitators. All plant interlocks are described in Appendix PP-1002.

The benefit of programming interlocks in this fashion is that they are active for both Station and Excel operation. Consequently the points that students are provided with for developing control strategies in Excel, all form part of unique interlock sequences. A ground level interlock will always take action given the event of an abnormal situation.

![Figure 22: Interlock programming for Needle Tank Pump](image)

### 5.4 PID FB Algorithms

The PID block located in the control tab of the FB library provides four different equations for calculating the PID algorithm. This is the PID block used for automatic control via Station and thus the best PID algorithm for student learning needs to be selected. The algorithm is changed via the FB parameters and once loaded to the C300 cannot be changed via Station. The four variants of the PID algorithm are presented from Equation 2 to Equation 5. The step response of each control algorithm...
is presented in Figure 24. Each algorithm is subject to a gain \( K = 5 \), Integral time constant \( T_1 = 5 \) minutes and derivative time constant \( T_2 = 2 \) minutes and is used to control a second order, under-damped simulated system with transfer function provided in Equation 7. Prior to considering each equation, it should be noted that each PID algorithm considers error to be \( (PV - SP) \) where as the traditional PID control algorithm refers to error as \( (SP - PV) \) (Ogunnaike & Ray, 1994). The effect this has on the final control algorithm is that the gain \( K \) is reversed. The following terminology in this report refers to the error as \( (PV - SP) \) and will not be discussed further.

Equation A:

This equation is most relevant for students studying Instrumentation and Control at Murdoch University. This is because the equation takes the form of what is taught at Murdoch University as a ‘traditional PID algorithm’. Consequently all three terms (Proportional, Integral and Derivative) act on the error \( (PV – SP) \) (Ogunnaike & Ray, 1994).

Equation A is formally known as the Parallel Incremental algorithm and differs from the traditional PID algorithm in that the error term is reversed and the derivative term is subject to a first order filter with gain of unity and time constant equal to \( (\alpha * T_2) \).

\[
CV = K * L^{-1} \left[ \left( 1 + \frac{1}{T_1 s} + \frac{T_2 s}{1 + \alpha * T_2 s} \right) * (PV - SP) \right]
\]

Equation 2: PID Algorithm A

Equation B:

Equation B differs in that the derivative term acts on the changes in PV while the proportional and integral terms continue to act on the error \( (PV – SP) \). This equation is beneficial when quick SP changes are implemented because with the derivative term acting on the changes in PV, the effect of derivative spikes are minimised.
Equation 3: PID Algorithm B

\[
CV = K \times L^{-1} \left[ \left( 1 + \frac{1}{T_{1s}} + \frac{T_{2s}}{1 + \alpha \times T_{2s}} \right) \times PVP - \left( 1 + \frac{1}{T_{1s}} \right) \times SPP \right]
\]

Equation C:

Equation C produces the smoothest response to SP changes, this is because unlike equations A and B, both the proportional and derivative terms act on changes in PV. The integral term remains acting on the error (PV – SP) and ensures minimal steady state offset.

\[
CV = K \times L^{-1} \left[ \left( 1 + \frac{1}{T_{1s}} + \frac{T_{2s}}{1 + \alpha \times T_{2s}} \right) \times PVP - \left( 1 + \frac{1}{T_{1s}} \right) \times SPP \right]
\]

Equation 4: PID Algorithm C

Equation D:

Equation D differs from all other equations in that it provides only integral control.

\[
CV = L^{-1} \left[ \frac{1}{T_{1s}} \times (PVP - SPP) \right]
\]

Equation 5: PID Algorithm D

The acronyms used in the various PID algorithms are defined in Table 6. It should be noted that the equations are in deviation form and thus the PID OP (CV), the Process Variable (PVP) and the Set Point (SPP) are in percentage units. Equations A, B and C all have the derivative term manipulated by a first order filter with gain of unity and time constant equal to (\(\alpha \times T_{2s}\)) as illustrated in Equation 6

\[
\text{Derivative Filter} = \frac{1}{\alpha \times T_{2s} + 1}
\]

Equation 6: 1st order Derivative Filter
Table 6: Acronyms used in PID equations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>Output of PID in percent</td>
</tr>
<tr>
<td>K</td>
<td>Gain (proportional term)</td>
</tr>
<tr>
<td>$L^{-1}$</td>
<td>Inverse of the LaPlace transform</td>
</tr>
<tr>
<td>PV</td>
<td>Process input value in engineering units</td>
</tr>
<tr>
<td>PVP</td>
<td>PV in percent</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>1/16 fixed filter constant.</td>
</tr>
<tr>
<td>s</td>
<td>LaPlace operator</td>
</tr>
<tr>
<td>SPP</td>
<td>Set Point in percent</td>
</tr>
<tr>
<td>T1</td>
<td>Integral time constant in minutes</td>
</tr>
<tr>
<td>T2</td>
<td>Derivative time constant in minutes</td>
</tr>
</tbody>
</table>

In confirming that the algorithms are accurate and the correct equation is selected, a MATLAB Simulink simulation was constructed to simulate the performance of each controller against a second order under-damped system. The system was modeled by the LaPlace transfer function presented in Equation 7. The Simulink model is provided in Appendix PP-2001, with response provided in Figure 24.

\[
Model\ \text{Systems\ Transfer\ Function} = \frac{1}{3s + 1s + 1}
\]

Equation 7: Model System Transfer Function
The responses of the different controller algorithms when subject to the same control parameters are as expected, with the traditional control algorithm of Equation A.

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resulting in the most aggressive response. It should be noted that the control parameters implemented were not selected by any formal method but rather randomly selected with the same parameters implemented on all controllers to illustrate the performance of the different algorithms. When the derivative acts on the change in PV, rather than the error (SP-PV) as in Equation B, the result is less aggressive which is the expected result as the derivative term of Equation B reduces faster than that of Equation A. As expected, Equation C resulted in the most sluggish performance out of all equations and is due to both the proportional and derivative terms acting on the rate of change in PV.

Equation A is the chosen control algorithm for the Pilot Plant, again this is because the equation is the most similar to the traditional PID control algorithm that is taught to engineering students at Murdoch University. This algorithm is presented in Equation 8.

\[ c(s) = Kc \left( 1 + \frac{1}{\tau_1 s} + \tau_D s \right) * \varepsilon(s) \]

Equation 8: Traditional PID algorithm at Murdoch University

where

\[ \varepsilon(s) = y_d(s) - y_m(s) \]

Equation 9: Error for traditional PID algorithm

The parameter relationships between Equation 2 and Equation 8 are:

\[ Kc = -K \]

\[ \tau_i = T1 \]

&

\[ \tau_D = \frac{T2}{1 + a + T2} \quad \text{or} \quad T2 = \frac{\tau_D}{1 - a + \tau_D} \]

Equation 10: Parameter relationships between traditional and parallel incremental PID algorithms
This relationship is provided in the Pilot Plant Station and Excel operator user guides so that engineering students understand how to implement conventional tuning rules for the station PID controller parameters.
CHAPTER SIX: HMI Design

At the completion of stage 3, the Pilot Plant was completely operational with both manual and automatic control operational via the monitoring tab of Control Builder. The project was nearing completion however the very important user display / operator screens needed constructing. It was suggested in Punch (2009) that the user display screens would be developed with respect to the Abnormal Situation Management (ASM) principles. Thus the user displays that were developed and implemented into the Pilot Plant were a continuation of the initial displays that Punch proposed. Chapter Six is structured to give an overview of the ASMs display design theory and alarm management principles. Implementing the guidelines and standards will then be considered with respect to the Pilot Plant user displays. This chapter is concluded by a brief illustration of trending in Station.

Appendix PP-5002 contains the user guides for operating the plant via the displays discussed in this chapter. Additionally SOPs are available via Appendix PP-3000 that illustrate how to configure points for historical logging and trending.

6.1 Design Theory - ASM guidelines

The Abnormal Situation Management Consortium, or more commonly the ASM is a group of more than 13 companies including Honeywell that together have undertaken extensive research in the field of Abnormal Event Guidance Information Systems (AEGIS) (Bulmer & Nimmo, 1998). One field of AEGIS that Honeywell specialise in with regards to Experion PKS suite is the human-machine interface (HMI). Traditionally HMI refers to the medium that interfaces humans to computers, consequently with respect to process control, HMI refers to the user displays that provide the interaction between the operator and the plant.
Conventionally human factors engineering of HMI s in processing plants is concerned with two design features. These being the ergonomics of the physical layer (physical design considerations) and secondly the graphical interface presented to the operator (cognitive design considerations) (Nimmo, 1995).

For the Pilot Plant, the ergonomics of the physical layer refers to the physical design of the control room. With the Pilot Plant currently being used as a teaching facility, an upgrade of the physical design of the control room is worth considering. For the time being the design of the control room is outside the scope of this project and therefore will not be considered further.

The cognitive design considerations however are directly related to the design of the new Pilot Plant operator display screens. One of the key issues in interfacing the plant with the operator is successfully communicating alarms. Thus a common denominator between all user displays is the need for operators to work efficiently and effectively in the event of an alarm.

The ASM Consortium developed a guideline approach to designing and improving plant operator displays which is part of their first publication, “Effective Operator Display Design”. Consortium members from the chemical and refining industries developed the guidelines in reflection of real-world experiences. The guidelines are targeted towards operations managers, operators, process engineers, system design engineers and safety and reliability engineers charged with improving interaction between automation systems and the people controlling the processes (PRWeb, 2009).

The guidelines suggest a four layer display hierarchy, with additional detail added to each layer. Application of the guidelines should produce both a broad overview of collective unit operations as well as detailed displays of individual unit operations (Nimmo, 1995). The Honeywell Experion PKS suite takes this into consideration and provides Asset grouping of unit operations at the DCS level. As a result, when
implementing Experion PKS for total plant control, the plant is broken into a number of Asset areas which aid in the implementation of the ASM display guidelines. The guidelines are listed in Table 7 and have been used to develop the Pilot Plant user displays. The architecture of the new Pilot Plant displays were first considered by Punch (2009) and have since been revised to incorporate levels one, two and four of the ASM guidelines.

Table 7: ASM display guidelines (ASM, 2008)

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
</table>
| Level 1: Process Area Overview Display | • Minimal detail is required to illustrate the broadest available view of the facilities under the operator’s control.  
• Primary purpose is to provide situational awareness of the operators entire span of control.  
• Summarize on a limited number of displays.  
• Contains multiple units, with the process values or safety signals being read-only from a control perspective. (thus operator cannot execute any control from this display).  
• Simplified process flow diagrams of the entire plant area. |
| Level 2: Process Unit Overview Display | • This is the main control interface for performing routine operational tasks.  
• Every major process unit requires a level 2 display.  
• Enough information must be present to control the plant under normal conditions.  
• Information regarding key elements of the process unit is displayed. |
| Level 3: Detailed Displays | • Level 3 displays are thorough in detail and contain all available information of smaller pieces of the process unit.  
• These displays are used for detailed investigations and interventions that are not time – critical.  
• These displays can show additional alarm detail if necessary. |
| Level 4: Specific Requirements | • Level 4 displays provide additional displays for any specific requirements such as:  
  • Information on operating equipment  
  • Information on unique equipment  
  • Information on unique unit ops. |
The Honeywell software that is used to develop the user displays offers integrated alarm management principles that directly reflect the research conducted by the ASM Consortium in AEGIS studies. The alarm management principles relate directly to colours, symbols and audible annunciation that the operator is subjected to. The principles effectively promote the use of these tools so that when an abnormal event occurs, the tools can draw an operator’s attention to unexpected process deviations. Additionally, the operator needs to be aware of the event with enough time to view the state of the process / alarm, and still have a safe amount of time to take action. In constructing an alarm philosophy, the ASM promote the idea of virtual momentum. Virtual momentum can be defined as a user’s ability to extract relevant information across a range of displays. Virtual momentum can be increased by improving the use of consistent graphical user interfaces (Nimmo, 1995). Thus, Honeywell along with the ASM encourage a ‘grey scale’ approach to constructing user displays.

The grey scale philosophy states that by using dull shades (grey) to represent normal operation then vibrant colours can be used to represent abnormal plant operation. This philosophy has guided the construction of the new Pilot Plant displays and thus colour is only used to highlight abnormal situations. In particular, the two colours yellow and red are used. Yellow is used to emphasize abnormal situations and the colour red is used to emphasize critical situations / danger.

6.2 Pilot Plant Operator Display Hierarchy

The display guidelines presented in Table 7 and discussed above were used to create the display hierarchy for the Pilot Plant. The hierarchy consists of levels one, two and four of the ASM guidelines and is illustrated in Figure 25. The level one display sits above all other displays and is the first screen viewed when Station is opened. This display is titled the “Overview display” and as expected provides a minimal detail, overview of the entire plant. If the plant is to expand then an additional level one screen
may be required but for the time being, the size of the plant permits a single level one display. Unique to this display is that all process values are read-only. Thus students cannot execute any control from this display. It is believed that this display will be very useful for students upon implementing control algorithms via Excel. Therefore the entire plant can be monitored via the overview display while controlled via an Excel spreadsheet.

Beneath the Overview display sits six detailed control displays. These displays have been constructed in consideration of level two and as such focus on individual unit operations. The screens are developed to be the main control interface for performing routine control operations on the plant. The screens are divided into the six main stages of the plant, being: Storage Tanks, Ball Mill stage, Cyclone stage, Needle Tank stage, CSTR bank and the Dye System. The displays differ slightly from the guidelines in that each control instrument has a manual / auto control faceplate. This was included to account for student learning and operation of the plant.

The lowest level in the hierarchy is another monitoring display and was constructed in consideration of level four of the ASM guidelines. This display monitors the VSD’s over the MODBUS link and is unique from all others in that no data is read through the
C300. Instead all data for the display is read from the SCADA MODBUS link. Thus if the C300 drops out then these vitals can still be received. The SCADA MODBUS link was discussed in chapter three.

6.3 Pilot Plant Operator Displays

Part of the Experion PKS software package is the HMIWeb display builder software. Within this environment, unique operator displays are constructed. Honeywell have developed the symbol libraries with respect to the ASM grey scale alarm management philosophy, and therefore offer pre constructed grey scale symbols with alarm and event colour notification pre configured. This software was used to develop all Pilot Plant displays. The final displays are illustrated in Figure 26. This figure illustrates the Overview page in the centre and a number of the layer two displays that are accessed via the overview stage.
Figure 26: Pilot Plant Operator Displays

Figure 27: VFD Overview display
The six, level two displays present far more detail than any other displays. This is necessary as these are the main operator control screens. A number of the key navigational tools are illustrated for the Storage Tank display screen in Figure 28.

![Diagram of Storage Tanks](image)

**Figure 28: Level two display (Storage Tanks)**

### 6.4 Alarming In Station

Analogue Lo, LoLo, Hi and HiHi alarms are configured for each tank. The user is notified by the alarm via the system plant alarms bottom toolbar as well as on the vessels digital level indicator.
A log of the alarms is maintained in the system and remains until the alarm is acknowledged and rectified.

Acknowledgement of the alarm can be achieved via the Ack Page button located on each user screen or by entering the log data base and acknowledging individual alarms.

It should be noted that a 5 second duration of a LoLo alarm for all tank levels will engage the safety interlocks for the pumps that feed out of the tank. These interlocks ensure safe operation of the pumps.

Figure 29: Station Display Alarms
6.5 Trending

For a point to be selected for trending it must first be configured for historical logging. Every Point Parameter used for Excel communication and included in Appendix PP-1001 is configured for trending. If historical data is required for an additional point then the point can be configured for historical assignment via following the steps in Appendix PP-3006. The three types of historical logging are Standard, Extended and Fast. The main differences between each type include: the interval in which the data is captured in, the duration the data is preserved for and the number of samples maintained. Each type is summarized in Table 8.

Table 8: Historical Data Logging Types (Honeywell, 2007b)

<table>
<thead>
<tr>
<th>History Type</th>
<th>Intervals</th>
<th>File Sizes</th>
<th>Number of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td></td>
</tr>
<tr>
<td>Standard History</td>
<td>1 – minute snapshot</td>
<td>24 hours</td>
<td>1442</td>
</tr>
<tr>
<td></td>
<td>6 – minute average</td>
<td>7 days</td>
<td>1682</td>
</tr>
<tr>
<td></td>
<td>1 – hour average</td>
<td>7 days</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>8 – hour average</td>
<td>3 months</td>
<td>281</td>
</tr>
<tr>
<td></td>
<td>24 – hour average</td>
<td>1 year</td>
<td>368</td>
</tr>
<tr>
<td>Extended History</td>
<td>1 – snapshot</td>
<td>7 days</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>8 – hour snapshot</td>
<td>3 months</td>
<td>281</td>
</tr>
<tr>
<td></td>
<td>24 – hour snapshot</td>
<td>1 year</td>
<td>368</td>
</tr>
<tr>
<td>Fast History</td>
<td>1 to 30 second snapshot</td>
<td>2 hours – 72 hours</td>
<td>8652</td>
</tr>
</tbody>
</table>
Each control display (level one or two display) has a pre configured trend page. The trends on each page are associated with the unit operations found on its associated control page.

The control page and trend page are associated as follows:

Table 9: Station Trend Pages

<table>
<thead>
<tr>
<th>Display Page</th>
<th>Trend Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display Overview (pg 301)</td>
<td>Overview (trend 1)</td>
</tr>
<tr>
<td>Storage Tanks (pg 302)</td>
<td>Supply Tanks (trend 2)</td>
</tr>
<tr>
<td>Ball Mill (pg 303)</td>
<td>Ball Mill Tank (trend 3)</td>
</tr>
<tr>
<td>Cyclone Stage (pg 304)</td>
<td>Cyclone Stage (trend 4)</td>
</tr>
<tr>
<td>Needle Tank (pg 305)</td>
<td>Needle Tank Stage (trend 5)</td>
</tr>
<tr>
<td>CSTR’s (pg 306)</td>
<td>CSTR Bank (trend 6)</td>
</tr>
<tr>
<td>Dye Tank (pg 307)</td>
<td>Dye System (trend 7)</td>
</tr>
</tbody>
</table>

As illustrated in Figure 31 and Figure 32, selected data can be copied (ctrl + c) and pasted (ctrl + v) into Excel. This is a fast way to capture historical data for further evaluation.
Figure 31: Station Trending

Figure 32: Exporting Data to Excel
When the data is imported into Excel its historical date and time is imported as well as the captured data points. This is illustrated in Figure 32. If a data point is required that is not already established for historical logging then the point will need to be configured. Historical and current data can also dynamically be updated into an Excel spreadsheet. This is achieved via cell formulas and is discussed in Chapter Seven.
CHAPER SEVEN: Excel Communication

7.1 Server Communication - Excel

Excel Communication is achieved via Honeywell's proprietary Microsoft Excel Data Exchange (MSEDE) application. The MSEDE option allows current point data, static or dynamic historical data to be imported from the server into a Microsoft Excel spreadsheet. This is the preferred method of server communication as Honeywell have developed a user-friendly wizard that makes using MSEDE a simple process.

MSEDE operates on the Network Server which provides access to the PlantScape Vista database. The Network Server is a function of Open Data Access (ODA) and thus considered a 'user' of ODA. Other users of ODA include the ODBC driver which allows the server to be queried using SQL commands for ODBC client applications and the OPC server, which allows third-party OPC client applications to read/write to Vista point parameters (Honeywell, 2007b). As MSEDE provides the best solution for student use, this was the preferred method of communication and thus ODBC and OPC will not be considered any further in this document.

7.2 Microsoft Excel Data Exchange - Pilot Plant

For MSEDE to read and write to the server, both the client and server computers require configuring. PPServer1 was configured for read/write MSEDE functionality at the installation stage and is pre-configured for student use. Each client computer in the control room requires MSEDE software to be installed. This will be pre-loaded onto all computers in the control room prior to student use. Thus students are only required to include the MSEDE Wizard into the spreadsheet via Excel Add-Ins, in order to read/write plant data into an Excel spreadsheet on any computer in the control room. Appendix PP-3001 is an SOP for installing MSEDE. Once MSEDE is included in a spreadsheet, reading/writing plant data is achieved via two methods. These are using
the Wizard or using cell formulas. However both methods result in the same functionality. These are illustrated in the Excel user-guide of Appendix PP-5001, and result in seven user defined functions. These functions are shown in Table 10.

Table 10: Microsoft Excel Data Exchange Cell Commands

<table>
<thead>
<tr>
<th>Cell Command</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>GetHistVal_Date</td>
<td>Imports a single point of data offset by a specified date.</td>
</tr>
<tr>
<td>GetHistVal_Offset</td>
<td>Periodically imports a singly point of data offset by a specific value - continually updates.</td>
</tr>
<tr>
<td>GetHistValArray_Date</td>
<td>Imports an array of data points offset by a specified date.</td>
</tr>
<tr>
<td>GetHistValArray_Offset</td>
<td>Imports an array of data points offset by a specific value - continually updates.</td>
</tr>
<tr>
<td>GetPointVal</td>
<td>Imports a single point (most current point).</td>
</tr>
<tr>
<td>GetPointValArray</td>
<td>Imports an array of data points, with no offset.</td>
</tr>
<tr>
<td>PutPointVale_Number</td>
<td>Writes a single point.</td>
</tr>
</tbody>
</table>

This extensive list of cell commands provides all required means for implementation of Advanced Control Schemes into the Pilot Plant.

The electronic Appendix PP-2003 was constructed to illustrate the use of an Excel spreadsheet for implementing various control algorithms. The example spreadsheet implements a positional form PI control algorithm and illustrates the use of GetPointVal_Number, Get_HistValArray_Offset and PutPointVal_Number cell commands. A screen shot of the controller is provided in Figure 33.
Figure 33: Example PI control via Excel
CHAPTER EIGHT: Total Plant Commission.

In finalising the work conducted in this project, a total plant commission was performed. This commissioning was implemented on two levels. First, every interlock and alarm was tested via the station display screens, Secondly every point configured for reading / writing to via Excel was checked via the Excel total plant read / write spreadsheet which is included in Appendix PP-2002.

It was found that the Pilot Plant had a number of valves, both analog and digital, that were physically in need of attention, however the communication signals sent to the valves was operable. A list of the instruments in need of attention is provided in Table 11.

Table 11: Instruments requiring commissioning

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Fault description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCV-571</td>
<td>Valve Ceased – No Movement</td>
</tr>
<tr>
<td>FCV-622</td>
<td>Valve Ceased – No Movement</td>
</tr>
<tr>
<td>FCV-642</td>
<td>Valve Not operating over full range</td>
</tr>
<tr>
<td>3WV-143</td>
<td>Valve Ceased – No Movement</td>
</tr>
<tr>
<td>3WV-368</td>
<td>Valve Ceased – No Movement</td>
</tr>
<tr>
<td>3WV-428</td>
<td>Valve Ceased – No Movement</td>
</tr>
<tr>
<td>3WV-572</td>
<td>Valve Ceased – No Movement</td>
</tr>
</tbody>
</table>

A total plant read / write spreadsheet was also created as a means of starting commissioning the plant after the move to the new Engineering and Science building. Therefore if the plant is re-constructed correctly and the C300 / VFDs are not damaged then the Excel spread sheet for reading and writing directly to the plant will work. If not, then I wish the next engineering thesis student the best of luck and hope they too discover a bonding relationship with the Pilot Plant.
CHAPTER NINE: Proposed Future Projects

9.1 Fieldbus Instruments
One characteristic of the C300 and the IOTA is the ease in adding Honeywell modules.

One such module that has been considered for use in the Pilot Plant is a Fieldbus interface module (FIM). The FIM is designed to integrate open standards of FOUNDATION Fieldbus with the Experion PKS (Honeywell, 2007). Due to this, integrating FOUNDATION Fieldbus instruments into the already designed program should not be too challenging. The series C FIM attaches to the IOTA identically to the already existing IOMs and is illustrated in Figure 34. The module allows for all the traditional Experion tools including data access, control, diagnostic options and alarming with the Experion PKS system (Honeywell, 2007). This is considered the easiest future upgrade in that the module directly interfaces with Control Builder. Thus much like the previously discussed PCDI blocks, the Fieldbus and the Experion function blocks can be mixed and matched in the same control drawings.

![Figure 34: FOUNDATION Fieldbus module](Honeywell, 2007)
9.2 Wireless Instruments
Honeywell have developed the XYR 5000 Wireless series of instruments. The instruments can be used for accurately monitoring gauge pressure, absolute pressure or temperature. Additionally the wireless instruments can also be configured to include a 4-20 mA output signal (Honeywell, 2008d) which would be perfect for controlling any of the flow control valves in the Pilot Plant. The XYR 5000 instruments are designed to communicate directly with Experion PKS, as a result this line of wireless instruments would be a valuable addition to the instruments in the Pilot Plant and reflect the cutting edge wireless technology to which industry has recently been exposed.

Figure 35: XYR 5000 Wireless Instrument
(Honeywell, 2008d)
Conclusion

The Pilot Plant is an integral teaching facility for engineering students. Therefore it was vital that the C300 and Experion PKS upgrade was complete and the plant was up and running before the move to the new Engineering and Science building. The equipment implemented complements the Pilot Plant in providing a teaching facility that reflects the technology currently used in industry. Consequently this thesis project has not only advanced my knowledge of Distributed Control Systems (DCS) and Supervisory Control And Data Acquisition (SCADA) topologies, but also exposed myself to the management aspect of an engineering project. As this was a major project that would normally be tackled by a team of engineers in industry, time management became a major component in order to bring the project to a successful conclusion. This was a solo project and consequently I had to adapt my way of learning and thinking. I couldn’t rely on lecturers or tutors to guide my learning, but instead had to be self dependent and seek answers autonomously.

The new Experion PKS server is a big advancement on the old SCAN 3000 server. For engineering students using the plant the new server means that they can implement tighter control strategies. Students will be able to learn and implement advance model based control strategies through the Experion Profit Suite software. Prior to entering the work force, Murdoch engineers will be able to identify and relate to the same quality and level of operator displays, alarm management and data acquisition that is used in industry. Ultimately engineering students from Murdoch University will enter the workforce better equipped to acclimate to the engineering workplace.
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