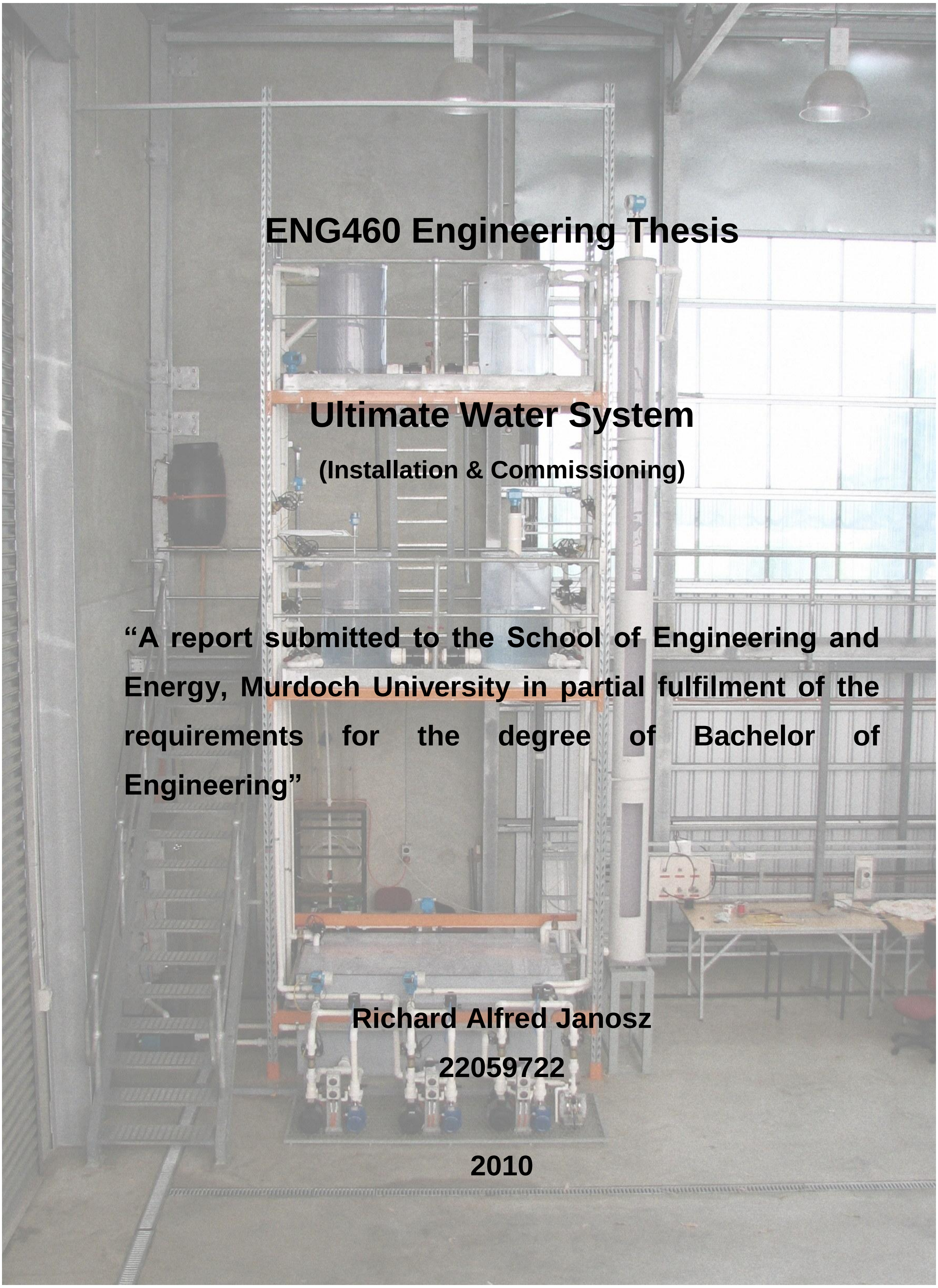

ENG460 Engineering Thesis

Ultimate Water System

(Installation & Commissioning)

"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"

Richard Alfred Janosz

22059722

2010

Abstract

The Ultimate Water System is destined to be a learning tool for engineering students to develop skills in control engineering. The system has been in design and various stages of construction for several years. However, before this thesis, the pumps had never been run and the instruments had never been mounted.

The plan for this thesis was to complete the installation of the instrumentation and electrical components of the Ultimate Water System to the point where the system could be run under automatic control. The control system and user schematics developed for this thesis would not be complex, but adequate to provide a commissioning interface for the system and prove the operation of the completed system in automatic control.

The control system hardware originally installed was no longer supported by National Instruments, so its replacement with a modern National Instruments controller was included in the thesis. This involved replacing the existing National Instruments Field-Point FP-2010 Real Time controller with a National Instruments CompactRIO 9012 controller. Retrofitting the CompactRIO controller required extensive control panel rework, including relocation of the control system on the panel, re-wiring and terminal modifications.

At the start of this thesis the Ultimate Water System had pipe-work mounted equipment such as pumps, flow meters, flow valves and flow control valves installed. However no level transmitters or level switches were fitted to the tanks. The instrument control panel had been wired for the original NI controller but not installed in the cabinet. No power wiring, instrument wiring or pneumatics had been installed between the cabinet and the system.

The plan to complete the required works under-estimated the time required for the controller and field equipment installation. This resulted in a reduction in the scope of the thesis. The revised thesis delivered a complete and operational

system with calibrated instrumentation and a LabVIEW commissioning program with proven control capability.

James Kurz, a fellow student, was completing his thesis based on the CompactRIO controller and HMI for the UWS in parallel with this thesis. The content of our work was discussed with Graeme Cole to ensure this course of action did not compromise our completed works.

Future enhancements for the system are included in this thesis. Some of the suggestions are considered necessary to enable the system to continue to operate such as the inclusion of filters to protect valves and flow meters.

Acknowledgments

Special thanks to John Boulton for his assistance with mechanical and electrical issues and background on the UWS, and also to Will Stirling for finding and supplying hardware and software for the project. Thanks to James Kurz who assisted in many of the activities to install the UWS. This thesis would not have been possible without their assistance.

Thanks also to Associate Professor Graeme Cole, the thesis supervisor, for his guidance and support throughout the project.

Thanks also to past students who have worked on the Ultimate Water System, their notes and reports were invaluable.

Contents

List Of Figures and Tables

1 Introduction and Literature Review

The Ultimate Water System is a teaching aid, designed and built by past students to benefit future students. The system has been designed to closely resemble an actual processing plant with control systems, field transmitters to relay plant data back to the control system, and control valves and pumps to modulate and move the process (water) around the plant. The tank pumps and valves installed in the UWS can be configured in many ways to present students with interesting control problems.

The design of the UWS has been under way for a number of years and many student groups have participated. The CHAD web site (Chad Server - Universal Water System) has extensive documentation regarding the work completed by these students and was regularly consulted to determine the philosophy behind many design aspects of the installed equipment. Many aspects of the control design contained in Chad were challenged and changed, primarily because of the replacement of the National Instruments Field-Point controller in the system.

The Ultimate Water System was constructed at the Rockingham campus but was never commissioned. It was relocated to the South Street Campus in 2008. The relocation did not include the re-installation of field instrumentation or cables. Previous students had designed and installed a National Instruments Field Point FP-2010 Real Time controller; however spare parts for this controller were no longer available from National Instruments. It was decided to replace the existing controller with a National Instruments CompactRIO 9012 controller and this was included to form part of the thesis. The main control panel which houses the CompactRIO and power equipment required extensive work. It had electrical components such as contactors and relays fitted; however no wiring had been installed. All field instruments mounted in the process pipe work, such as flow meters and solenoid and control valves, had been fitted into the pipe work during re-installation; however no wiring had been installed. The tank level transmitters and limit switches required mounting brackets, installation and electrical connections. All additional field wiring, except motor power cables, required installation and termination.

Added into this thesis are appendices detailing all electrical schematics and P&ID drawings for the UWS, the progress journal used to track progress throughout the project, LabVIEW control commissioning programs and schematics and a complete set of data sheets on installed instruments.

2 The Ultimate Water System

The Ultimate Water System comprises:

- 6 tanks
- 9 pumps
- 17 controlled valves
- 7 flow meters
- 6 level transmitters
- 1 weight transmitter
- 11 tank level switches
- Interconnecting pipes and block valves
- National Instruments CompactRIO Control System

Pumps PU01, PU03, PU05, PU08 and PU09 are positive displacement pumps, PU02, PU04 and PU06 are centrifugal pumps and pump PU07 is a pneumatically operated diaphragm pump. All pumps, except the diaphragm pump, are electrically actuated by motors. The positive displacement pumps are fitted with variable speed drives to control the flow delivered by the pump.

The physical construction of the UWS is arranged into 3 levels as shown in Figure 1. The main tank, Tank 06, is the reservoir and is on the ground (first) floor. Immediately above the reservoir are Tanks 03 and 04 on the second floor and directly above these are Tanks 01 and 02 on the third floor. Tank 05, which is a tall tank, is situated on the west end of the system and is approximately 5.8 meters high. Refer to drawing UWS-0001 Ultimate Water System Piping and Instrument Drawing.

The system has basic limitations concerning maximum pressures which must not be exceeded in the pipe work. Common pipe work exists in the discharge of pumps PU01 / PU02, pumps PU03 / PU04 and pumps PU05 / PU06 and PU07. If these pumps are running concurrently then a pipe work over pressure condition could occur. Pipe work overpressure due to multiple pumps operating in the same system or incorrect valve operation is mitigated using a software interlock to prevent such an occurrence.

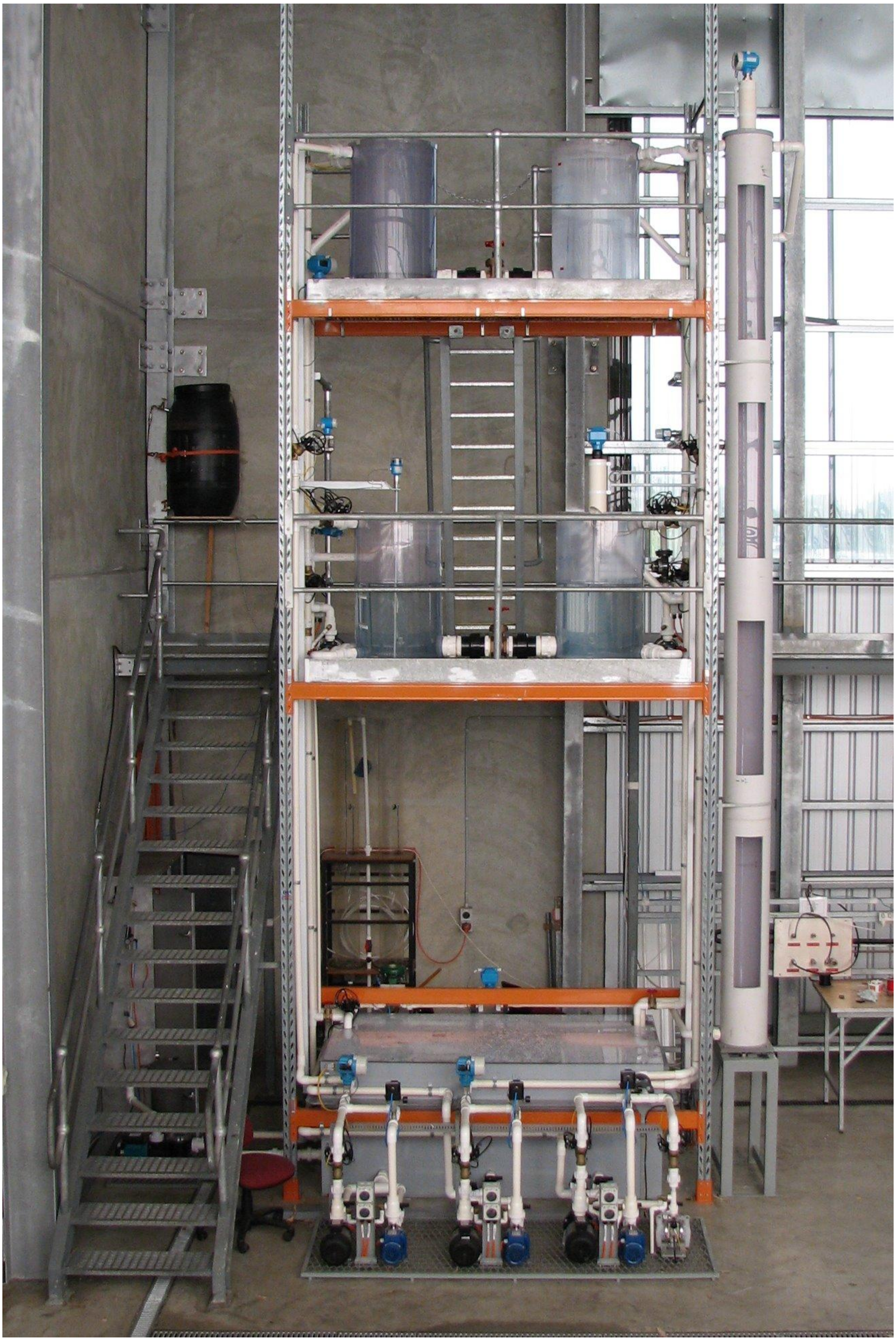

Figure 1 The Ultimate Water System

The pipe work configuration divides the UWS into 3 basic systems. The first system comprises pumps PU01 and PU02, which draw water from the reservoir and pumps to tanks 01 and 03. The second system comprises pumps PU03 and PU04, which draw water from the reservoir or the discharge from tank 05 and pumps to Tanks 02 and 04. The third system comprises pumps PU05, PU06 and PU07, which draw water from the reservoir or the discharge from Tanks 01 or 03 and pumps to Tank 05. Two additional pumps in the system allow for recycling water within the system: PU08 allows water to be transferred from Tank 04 to Tank 02; and PU09 allows water to be transferred from Tank 03 to Tank 01.

Water can be diverted around the system by opening gate and ball valves. Gate valves are used to divert water between the various vessels and ball valves are used for pump isolation. Diversion of water between the vessels opens interesting control system possibilities due to the water flow interaction between the vessels. Solenoid operated valves are installed to allow the control system to divert water to the various tanks and ensure over pressure constraints are maintained. Control valves are installed to allow the control system to modulate flow in a controlled manner within the system.

All tanks are fitted with level transmitters which have been calibrated to deliver tank level as a percentage of the useable tank volume. That is, from the base of the tank when it is fully drained to the start of the overflow outlet.

Tank 01 is fitted with a differential pressure transmitter. It measures the difference in pressure between its negative and positive pressure inlet ports. The positive port is connected to the base of the tank and the negative port is vented to atmosphere. The head pressure of the water above the positive input port is measured by the transmitter and inferred as tank water level. Tank 02 is fitted with a similar instrument. However it has no negative pressure input and transmits pressure only. This transmitter measures the head pressure of water above its pressure input port. Refer to section 3.2.1 for more information.

Tank 03 is fitted with a capacitance level transmitter. This transmitter measures the change in capacitance due to the change in the level of the water surrounding the instruments level sensing probe. The measuring depth of the instrument is limited by the length of the probe and the accuracy of mounting the instrument in a location to position the level sensing probe close to the base of the tank. (Refer to section 3.2.2).

Tank 04 is fitted with an ultrasonic level transmitter. These transmitters utilize high intensity sound pulses reflected from the liquid surface. The time taken for the pulse to travel from the transmitter to the surface of the liquid and back is used to determine the level in the tank. The transmitter is supplied with mounting and tank details enabling it to calculate the tank level. (Refer to section 3.2.3).

Tank 05 is fitted with two transmitters. A load cell to measure weight and a radar level transmitter. The load cell is installed at the base of the tank. The transmitter connected to the cell is calibrated by trial, where filling and emptying the tank is carried out to determine the output parameters of the cell. The tank is also fitted with a radar level transmitter. It’s operating principle is very similar to the ultrasonic transmitter except it uses electromagnetic transmission rather than sound. It too is supplied with mounting and tank details that enable it to calculate the tank level. (Refer to section 4.5).

The main pipes from the sets of pumps to the tanks are fitted with flow meters. These are installed because these flows are modulated and require measurement for control applications to be developed. Flow meters FIT01, (Flow Indicating Transmitter 01), FIT02 and FT03, (Flow Transmitter 03), measure flow from the respective main pumping systems into the tanks of the UWS. FIT04 measures the recycle flow from Tank 03 to Tank 01 via pump PU09. Flow meter FT05 measures recycle flow from Tank 04 to Tank 05 via pump PU08. Flow meter FIT06 measures the discharge flow from Tank 05. Flow meter FIT07 measures the discharge from Tank 01 to either Tank 03 or the reservoir.

All tanks are fitted with High and Low level switches to indicate level status of the level in the tanks and provide future controls, alarms and interlocks for the pumps.

A National Instruments CompactRIO Controller will be used to provide process control for the Ultimate Water System, including pump over pressure interlocking and interface to all instrumentation, valves, flow transmitters and level transmitters. It will provide a platform for students to develop automatic control systems (Section 3.1).

3 Ultimate Water System Instrumentation

3.1 CompactRIO Control and Acquisition System

The CompactRIO control and acquisition system is a small yet powerful embedded process control and data acquisition system, (see Figure 2). The system interfaces with National Instruments LabVIEW graphical programming software for programming and operational interface. It features high density I/O with very small size and power requirements. The system can operate stand alone or as part of a distributed control system. Communications is via Ethernet. (National Instruments, 2010)

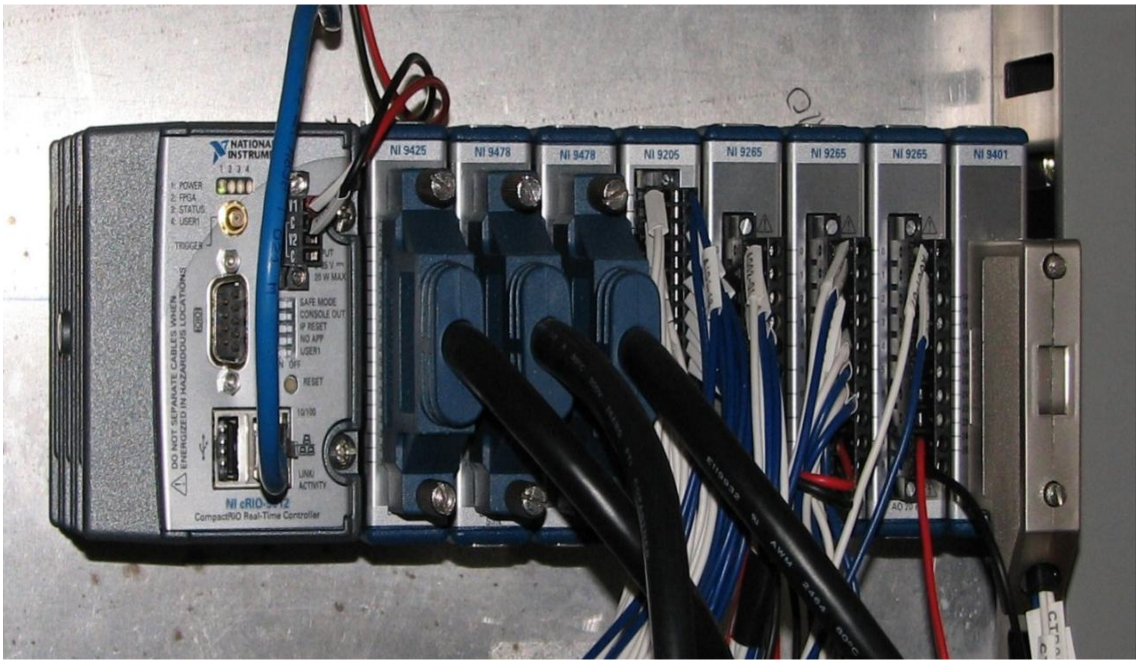

Figure 2 CompactRIO controller installed in the UWS

3.1.1 **CompactRIO NI cRIO-9012/9014 Controller**

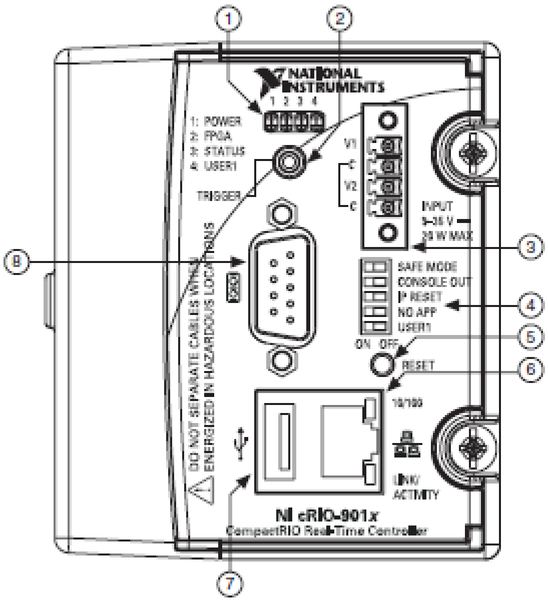

Figure 3 CompactRIO cRIO-9012/9014 (National Instruments, 2006a)

The CompactRIO controller, (see Figure 3), is the central processor for the control system and provides an interface for LabVIEW programming and process monitoring software. The controller also provides the functions outlined below:

1. Indication LEDS
    1. Power On LED: this is a two colour LED; green indicates the unit is powered from V1; yellow indicates the unit is powered from V2.
    2. FPGA LED: this can be programmed for application and program debugging.
    3. Status LED: the controller indicates specific errors by flashing this LED, refer to the cRIO-9012/9014 Operating Instructions and Specifications handbook for decoding error messages.
    4. USER1 LED: this LED indicates that the user 1 DIP switch is ON and a user defined function is in progress.

2. SMB Connector.

The SMB connector is used for connecting other digital devices to the controller. This functionality is not used in this thesis.

3. Power Connection terminals.

4. DIP Switches.

- SAFE MODE: This DIP switch is used only if the controllers program is corrupted. If the controller is powered up in this mode the controller only launches the programs used for configuration updating and software installation. The initial set up of the controller uses this switch so that the operating program can be loaded.
- CONSOLE OUT: This DIP switch is used to identify the controller when using a terminal program. The serial port terminal program will display the IP address and firmware version of the controller. This switch may be activated and deactivated during operation.
- IP RESET**:** Powering up the controller with the reset DIP switch in the ON position resets the controller's ethernet IP address to 0.0.0.0. A new IP address can be configured using LabVIEW's Measurement & Automation Explorer, (MAX).
- NO APP: This DIP switch, when in the ON position, prevents the controller from running a startup application immediately after power up. Applications that start when the controller is powered on must be created in LabVIEW.
- *User 1*: The effect of this DIP switch is user defined. Programming the effect of the switch is completed in LabVIEW by including the RTRead Switch VI in the program.

5. Reset Button. The reset button electronically resets the controller, the same function as cycling the controller power.

6. RJ45 Ethernet Port.This is the main communication port of the controller.

7. USB Port. The CompactRIO supports USB mass storage devices mapped in FAT16. These are not used in this thesis.

8. RS232 Serial Port. The RS232 port is used for connection of input devices or displays: it is not used in this thesis. (National Instruments, 2006a)

3.1.2 **CompactRIO 9112 Reconfigurable Embedded Chassis**

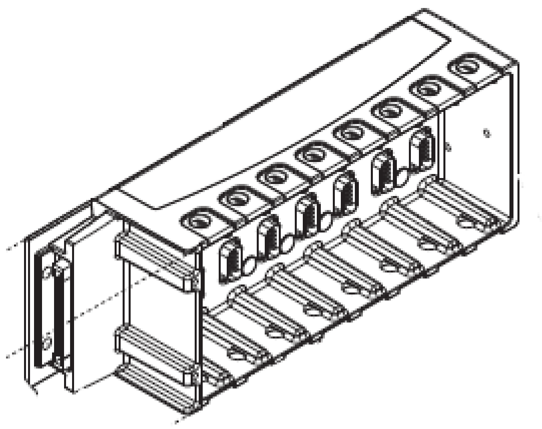

Figure 4 CompactRIO Embedded Chassis (National Instruments, 2009)

The CompactRIO chassis, (Figure 4), is the main mounting structure of the controller assembly and I/O modules. The CompactRIO controller mounts to the left hand side of the chassis with the input and output cards of the controller fitted into the remaining slots provided in the chassis. I/O cards are not keyed into any particular position in the chassis. They may be plugged into any slot and the chassis will identify and communicate with them regardless of position. Once programming is complete the type of card installed in a particular slot must remain the same because the inputs and outputs are coded by module number. (National Instruments, 2010c)

The CompactRIO chassis has embedded processing capability, which is a reconfigurable FPGA core located in the chassis. This core has individual connections to each I/O module over which it can perform read and write functions. The term FPGA refers to Field Programmable Gate Array. The array installed in the CompactRIO chassis operates independently of the processor; it can perform local processing and communicates directly with the I/O modules. These arrays operate very rapidly with a typical clock frequency of 200MHz. In FPGA configuration, the CompactRIO controller operates to log and pass data to and from the LabVIEW programs (National Instruments, 2009). The Embedded chassis installed in the Ultimate Water System is a model CRIO – 9112, 8 slot Virtex-5 LX 30 Reconfigurable Chassis for CompactRIO.

3.1.3 **NI 9425 Digital Input Module**

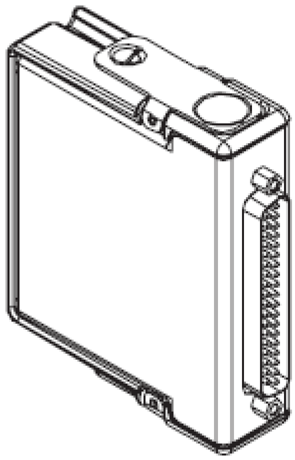

Figure 5 NI9425 Digital Input Module (National Instruments, 2008)

The Ultimate Water System utilizes one National Instruments NI 9425 32 Channel 24 Volt Sinking Digital Input Module, this module is located in slot 1 of the CompactRIO embedded chassis. The module has limited available space for connection terminals, therefore it is supplied with a remote field termination panel; the termination panel is connected to the module via a multi core cable and connector.

This device has sinking inputs. When the voltage applied to the input terminal is greater than 10VDC with respect to COM, the module senses an ‘ON’ state. If the applied voltage is less than 10VDC, with respect to COM, the module senses on ‘OFF’ state, this is shown in Figure 6, (National Instruments, 2008). The Ultimate Water System control panel uses 24VDC for digital input switching.

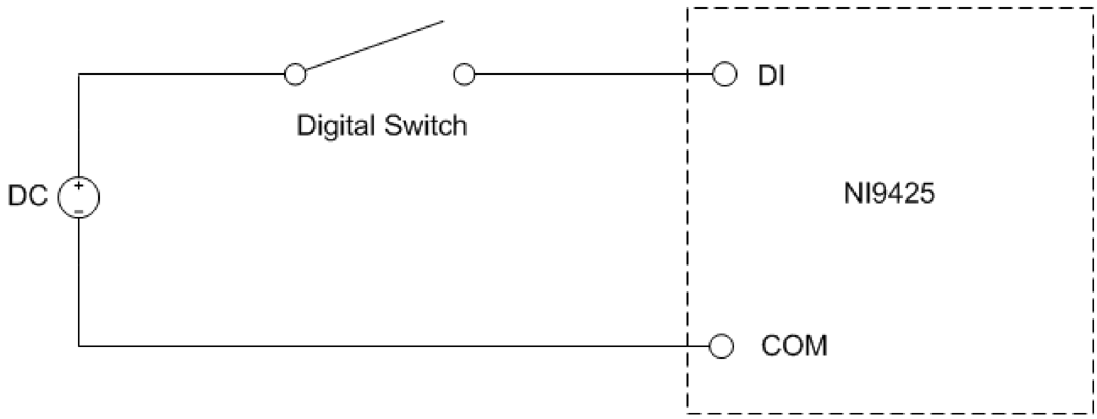

Figure 6 NI9425 DI Connection Diagram (National Instruments, 2008)

Slot 1 of the CompactRIO controller contains an NI0425 Digital Input Module and has the following Digital Inputs:

Module 1	NI 9425 Digital Input Module
Channel	Input Description
0	Tank 01 High water level switch
1	Tank 01 Low water level switch
2	Tank 02 High water level switch
3	Tank 02 Low water level switch
4	Tank 03 High water level switch
5	Tank 03 Low water level switch
6	Tank 04 High water level switch
7	Tank 04 Low water level switch

8	Tank 06 High water level switch
9	Tank 06 Low water level switch
10	Tank 01 Low - Low water level switch
11	SPARE
12	SEW VSD01 fault contact
13	Pump PU02 status
14	SEW VSD02 fault contact
15	Pump PU04 status
16	SEW VSD03 fault contact
17	Pump PU06 status
18	SEW VSD04 fault contact
19	SEW VSD05 fault contact
20	Filter pump status
21	SPARE
22	SPARE
23	SPARE
24	SPARE
25	SPARE
26	SPARE
27	SPARE
28	SPARE
29	SPARE
30	SPARE
31	SPARE

3.1.4 **NI 9478 Digital Output Module**

The Ultimate Water System utilizes two National Instruments NI 9478 16 Channel, 0 – 50V, Sinking Digital Output Modules. These modules are located in slots 2 and 3 of the CompactRIO embedded chassis. The module has limited available space for connection terminals. Therefore it is supplied with a remote field termination panel. The termination panel is connected to the module via a multi core cable and connector when the remote IO is used.

This device has sinking outputs. The output terminals are driven to the common ground potential when the outputs are turned on. The common terminal provides the return current path for the sinking outputs. Each channel has a common terminal and all of these terminals are connected to the common to prevent high currents flowing in the wiring loom should only one common be connected (National Instruments, 2007). Wiring connections for this module are shown in Figure 7.

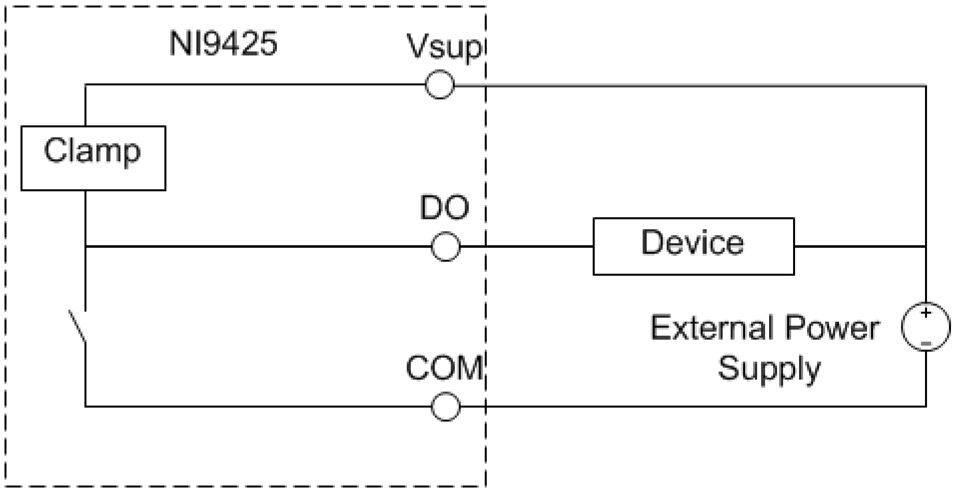

Figure 7 NI9425 Digital Output Module Connection Diagram.

Slots 2 and 3 of the CompactRIO controller contain NI9478 Digital Output Modules and have the following Digital Outputs:

Module 2 Channel	NI9478 Digital Output Module Description
0	Run pump PU02
1	Run pump PU04
2	Run pump PU06
3	Run filter pump
4	Pulse diaphragm pump PU07

5	SPARE
6	SPARE
7	SPARE
8	SPARE
9	SPARE
10	Run SEW VSD1
11	Run SEW VSD2
12	Run SEW VSD3
13	Run SEW VSD4
14	Run SEW VSD5
15	Turn on tank lights

Module 3	NI9478 Digital Output Module
Channel	Description
0	Solenoid Valve 01
1	Solenoid Valve 03
2	Solenoid Valve 05
3	Solenoid Valve 07
4	Solenoid Valve 09
5	Solenoid Valve 12
6	Solenoid Valve 13
7	Solenoid Valve 14
8	Solenoid Valve 15
9	Solenoid Valve 16
10	Solenoid Valve 17
11	Solenoid Valve 18
12	Solenoid Valve 19
13	Spare
14	Spare
15	Spare

3.1.5 **NI 9205 Analogue Input Module**

The Ultimate Water System utilizes one National Instruments NI 9205 32-Channel, +/-200mV to +/- 10V, 16-Bit Analogue Input Module. The module is located in slot 4 of the CompactRIO embedded chassis. The module can be configured for 32 open ended inputs or 16 differential inputs. In this particular application the inputs are configured for differential input operation (National Instruments, 2006b). The differential input configuration was selected because it has high common mode noise rejection, particularly because of the SEW variable speed motor drives which are installed in the control cabinet. Variable speed drives are notorious generators of electrical noise.

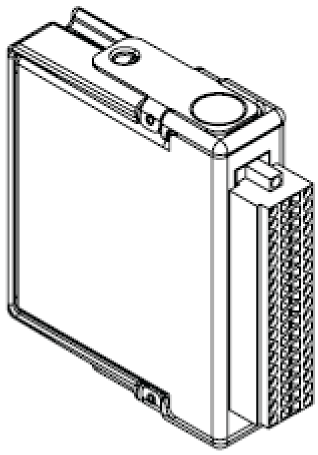

Figure 8 NI9205 Analogue Input Module. (National Instruments, 2006b)

Flow and level transmitters installed in the system all transmit data signals in scaled 4-20mA current. The transmitted current is characterised by passing the current through high accuracy 500 ohm resistors. The resulting volt drop across the resistors (2 – 10 Vdc) is the input to the particular channel in the analogue input card. The weight transmitter transmits the tank weight in a scalar +/- 10 volt signal and therefore no characterisation is required. The McNaught flow transmitters do not have an analogue output, they have a pulsed outputs which are routed to digital input module 8.

Slot 4 of the CompactRIO controller contains an NI9205 Analogue Input Module and has the following Analogue Inputs:

Module 4	NI9205 Analogue Input Module
Channel	Input Description
0	Flow Meter 01
1	Flow Meter 02
2	Flow Meter 04
3	Flow Meter 06
4	Flow Meter 07
5	Tank 01 Level Transmitter
6	Tank 02 Level Transmitter
7	Tank 03 Level Transmitter
16	Tank 04 Level Transmitter
17	Tank 05 Level Transmitter
18	Tank 05 Weight Transmitter
19	Spare
20	Spare
21	Spare
22	Spare
23	Spare

The numbering of the channels in the module are arranged for Open Ended Input connections, however differential input connections are used in this project. Channel numbers when differential input connections are used are not in perfect sequence as is evident in the Module 4 channel numbering given above. The channels are numbers this way because of the input connection terminal arrangements as displayed below in Figure 8. Differential inputs utilise 2 single ended inputs per channel. The channel numbering is as per the terminals on the left hand side of the connection module, refer to Figure 9.

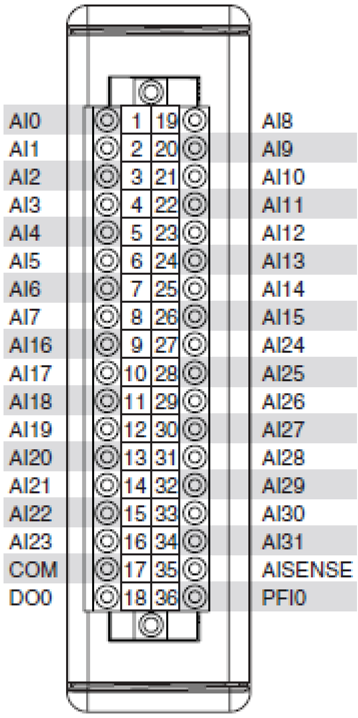

Figure 9 NI 9205 Terminal Assignments. (National Instruments, 2006b)

Flow and level transmitters are available in two distinctive arrangements: loop powered and non loop powered systems. Loop powered instruments are supplied with power from the loop in which they are operating. That is, a part of the current being circulated in the loop transmitting data is actually being used to power the transmitter. Transmitters which are not loop powered require a separate power supply, usually 24 VDC, and the current transmitted in the signal loop is only used for the transmission of data. This project uses both loop and separately powered transmitters. They require different connections as can be seen in

Figure 10 Loop Powered Transmitter and in Figure 11 Powered Transmitter Connection. .

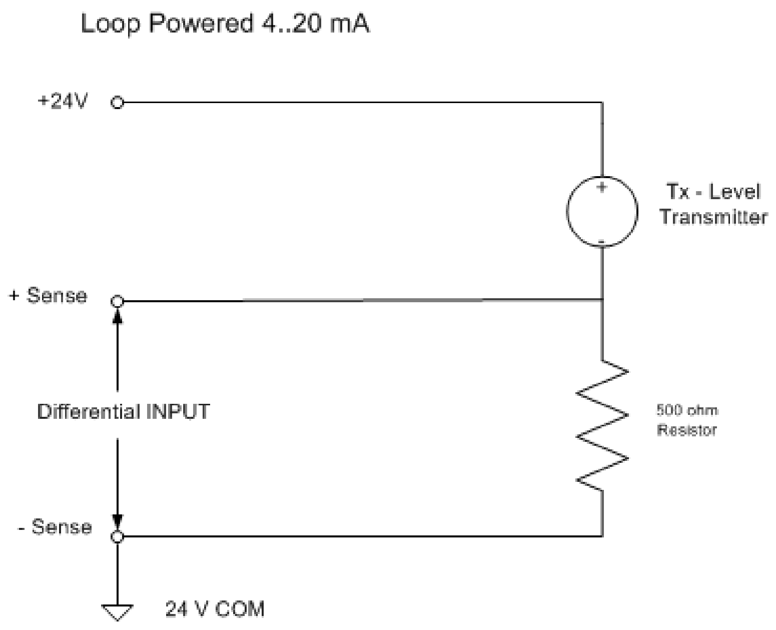

Figure 10 Loop Powered Transmitter (National Instruments, 2006b)

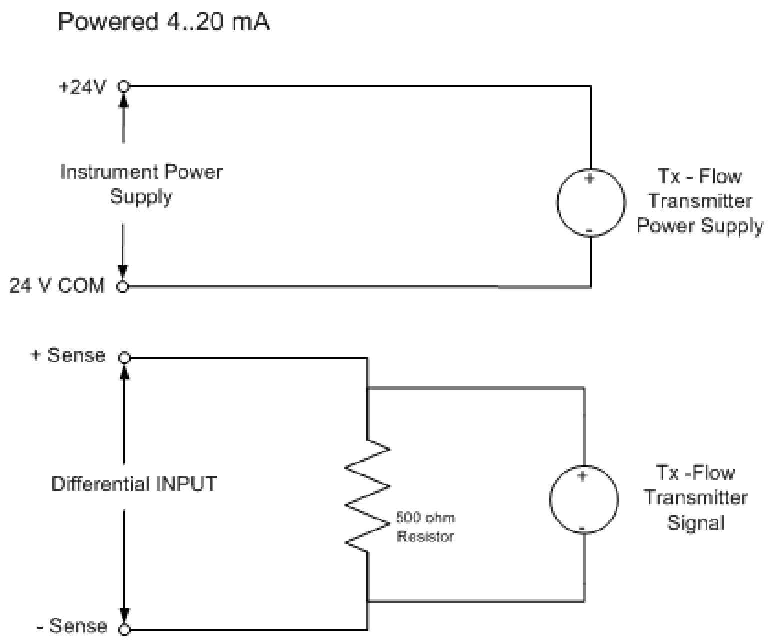

Figure 11 Powered Transmitter Connection. (National Instruments, 2006b)

3.1.6 **NI 9265 Analogue Output Module**

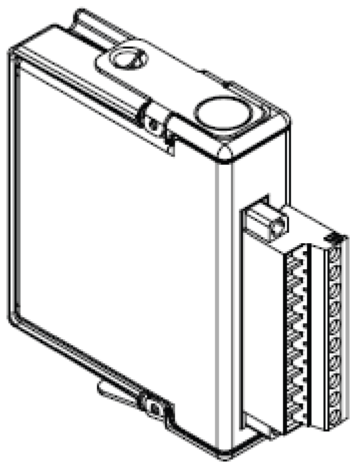

Figure 12 NI9265 Analogue Output Module. (National Instruments, 2005a)

The Ultimate Water System utilizes three National Instruments NI 9265 4 Channel, 0-20mA, 16 Bit Analogue Current Output Modules. These modules are located in slots 5, 6 and 7 of the CompactRIO embedded chassis. The modules are pre-configured to produce an output current of 0 – 20mA. Control valves and variable speed drives installed in the Ultimate Water System require a scaled 4-20mA control input for operation. The mismatch between the analogue output ranges and the input requirements of the controlling devices was removed by manipulation of the LabVIEW analogue output range configuration for each of the output channels. (National Instruments, 2005a)

Slots 5, 6 and 7 of the CompactRIO controller contain NI9265 Analogue Output Modules and have the following Analogue Outputs:

Module 5 Channel	NI9265 Analogue Output Module Description
0	Flow control valve 01
1	Flow control valve 02

2	Flow control valve 03
3	Flow control valve 04

Module 6 Channel	NI9265 Analogue Output Module Description
0	Variable speed drive 1
1	Variable speed drive 2
2	Variable speed drive 3
3	Variable speed drive 4

Module 7 Channel	NI9265 Analogue Output Module Description
0	Variable speed drive 5
1	SPARE
2	SPARE
3	SPARE

3.1.7 **NI 9401 TTL Digital Input / Output Module**

The Ultimate Water System utilizes one National Instruments NI 9401 8 channel TTL Digital Input / Output Module. The module is located in slot 8 of the CompactRIO embedded chassis. The module has 8 channels that can be individually programmed for either input or output functions. Each channel has a pull-down resistor and includes over voltage, over current, and short-circuit protection. The maximum switching or counting frequency for 4 channels is 16MHz (National Instruments, 2005b). This module was installed to count the pulses from the McNaught flow meters, FT03 and FT05. Figure 14 shows simplified wiring for the inputs to the module.

Slot 8 of the CompactRIO controller contains an NI9401 TTL Digital Input / Output Module and has the following Digital Inputs:

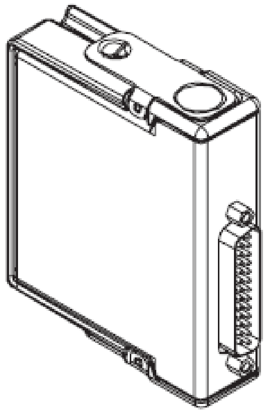

Figure 13 NI9401 Digital I/O Module (National Instruments, 2005b)

Module 8 Channel	NI9401 TTL Digital Input / Output Module Input Description
0	Flow Transmitter FT03 Signal A output
1	Flow Transmitter FT03 Signal B output
2	Flow Transmitter FT05 Signal A output
3	Flow Transmitter FT05 Signal B output
4	SPARE
5	SPARE
6	SPARE
7	SPARE
8	SPARE

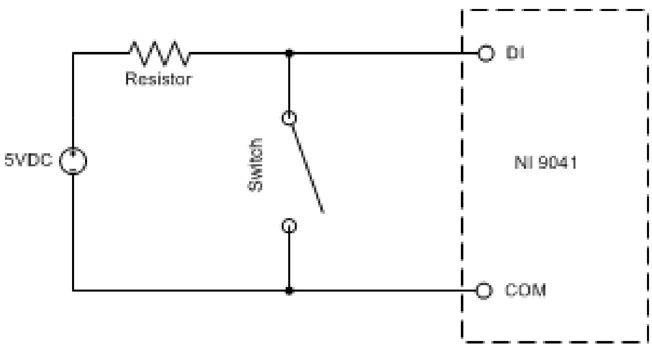

Figure 14 NI 9401 Input Circuit Schematic (National Instruments, 2005b)

3.2 Level Transmitters

3.2.1 **Pressure Transmitters**

Two different types of pressure transmitters have been used in the Ultimate Water System. They are the Endress & Hauser Deltabar S Differential Pressure transmitter and the Endress & Hauser Cerabar M Pressure transmitter. The level of the liquid in the tanks is inferred by the pressure measured by these transmitters. The Deltabar S Differential Pressure transmitter is fitted to Tank 01 and the Cerabar M Pressure transmitter is fitted to Tank 02. Pressure transmitters are used extensively in industry to measure level and pressure of liquids, vapours, gasses and solids.

The Deltabar S is a differential pressure transmitter. It has a low pressure and high pressure process connection which act as inverting and non inverting inputs. Pressure applied to the HI connection increases the output of the pressure transmitter, pressure applied to the LOW connection of the transmitter reduces the output. Differential pressure transmitters are used for measuring levels in pressurised vessels where the static pressure of the vessel causes more complexity in measurement. Transmitters are installed so that the static pressure in the tank is impressed on the high and low pressure inputs of the transmitter. The bottom tapping point is connected to the HI (non-inverting) input of the transmitter and the LO (inverting) input of the transmitter is connected to a tapping point at the top of the vessel. The static pressure is cancelled out and the transmitted pressure is the differential of the two inputs caused by the level in the vessel. (ENDRESS & HAUSER, 2003b) (ENDRESS & HAUSER, 2004).

The Cerabar M is a pressure transmitter. It has one non-inverting process connection. Pressure applied to the input increases the output of the transmitter. Pressure transmitters can be used to transmit tank levels provided the tanks are vented to atmosphere, as is the case with the Ultimate Water System tanks. (ENDRESS & HAUSER, 2003) (ENDRESS & HAUSER, 2003a).

The Deltabar S and the Cerabar M transmitters work on the same principles but have very different primary measuring elements. The Deltabar primary measuring element consists of two diaphragms with a silicon oil fill between them. When pressure is applied to either diaphragm force is applied to a measuring resistance bridge. The transmitter calculates the pressure from the magnitude of the resistance change.

The Cerabar primary measuring element consists of a ceramic diaphragm assembly in close proximity to an electrode mounted on a ceramic substrate. As pressure is exerted on the diaphragm it moves closer to the substrate (and electrode). Changes in the capacitance between the diaphragm and electrode are measured and the pressure is calculated.

Span Determination: To determine the pressure calibration requirements for the transmitters the following approach was used. The height of the tank or range over which the transmitter is required to operate and the density of the measured liquid at operating temperature are required.

Since $P = \rho . g . h$ where P = pressure (Pa)

ρ = density (kg/m^3)

g = gravity (9.81 m/s^2)

h = calibration height (m)

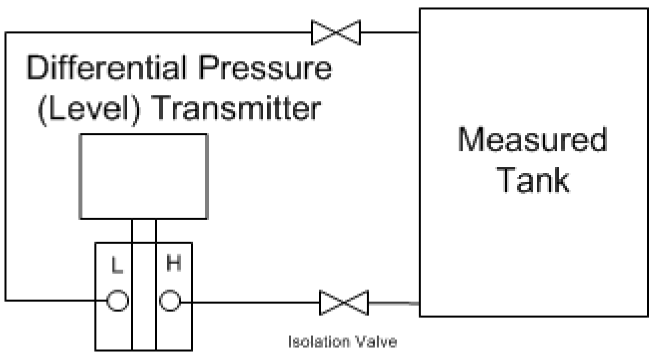

Figure 15 Differential Pressure Transmitter Process Connections

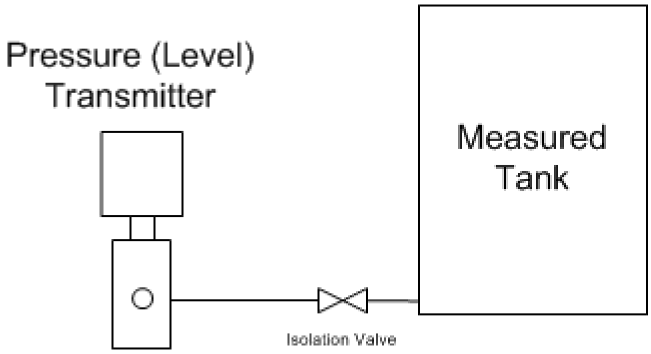

Figure 16 Pressure Transmitter Process Connections

Figure 17 Deltabar S

Figure 18 Cerabar M

3.2.2 **Capacitance Level Transmitter.**

Tank 03 is fitted with an Endress & Hauser Liquicap M Capacitance level transmitter with HART capability. The capacitance transmitter works on the effects of Gauss's Law. The capacitance of a circuit is proportional to the dielectric constant of the electrolyte times the area of the plates divided by the distance between the plates. In this case the water is the dielectric. As the level in the tank changes so does the surface area of the level probe in contact with electrolyte and the tank wall, thus the capacitance of the level probe and tank wall changes. The measured capacitance is proportional to the level in the tank. The capacitor level transmitter's probe is one of the active capacitor plates and is insulated to remove errors caused by the conductance of the water. Typical excitation frequency of capacitance probes is between 30kHz and 1MHz.

Endress & Hauser advise against using a fully insulated type of rod probe when measuring the level in a plastic tank, as used in the Ultimate Water System. A probe with a grounding tube is more suitable (ENDRESS & HAUSER, 2003c). The installed level transmitter does however work. The most plausible explanation is that the transmitter is using the metal flooring on which the tank is mounted as the other plate in the capacitance circuit.

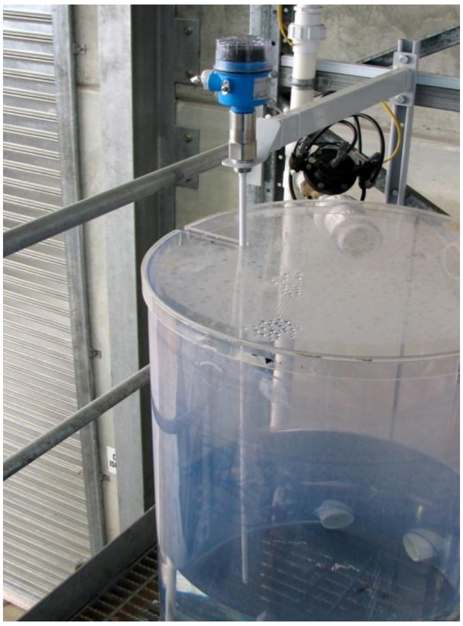

Figure 19 Tank 03 Liquicap M Capacitance Level Transmitter

3.2.3 **Ultrasonic Level Transmitter**

Tank 04 is fitted with an Endress & Hauser Prosonic M level transmitter. The ultrasonic level transmitter is designed for continuous level measurement and utilises the time of flight method of operation. The transmitter measures the time of flight of a high energy high frequency sound burst from the transmitter to the target (level of the liquid) and back.

$$D = v * t/2$$

Where D= distance to fluid level

t = time

v = speed of sound in air (Metres/Second)

SPAN = measurement span in meters

$$Level = \frac{100 \times (SPAN - D)}{SPAN}$$

Variations in air temperature change the velocity of sound in air. To counter this, temperature compensation is available via a temperature sensor installed in the pulse transducer. The transmitter is calibrated by entering the distance the liquid is from the transmitter when the tank is empty and entering the distance from the transmitter to the liquid when the tank is full. The transmitter calculates and transmits a 4-20mA signal proportional to the liquid level in the tank. The transmitter must be mounted so that the surface of the liquid is at least 150mm from the transmitter when the tank is full. The transmitter must switch from transmit to receive mode each time a pulse is emitted from the transducer. The distance travelled by sound in this switching time is within 150mm. This distance is known as the blanking distance. (ENDRESS & HAUSER, 2004) (ENDRESS & HAUSER, 2005).

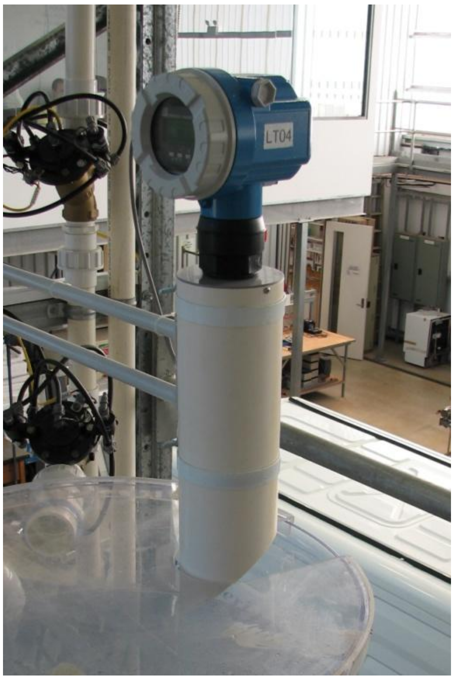

Figure 20 Tank 04 Prosonic M Ultrasonic Level Transmitter

3.2.4 **Radar Level Transmitter**

Tank 05 is fitted with an Endress & Hauser Micropilot M Radar level transmitter. The radar level transmitter's operation is similar to that of the ultrasonic level transmitter in that it employs time of flight to determine distance and thus level. The difference between the two instruments is that the radar level transmitter transmits pulses of electromagnetic energy. The frequency is typically 10GHz. The transmitter pulses the energy to gain snap shots of the level. It is designed for continuous level measurement so the measurements are averaged to give a continuous output signal. Other radar level transmitter designs employ Frequency Modulated Continuous Wave, (FMCW) measuring technology. These transmitters use much more power and so require an additional 24VDC power supply. However the measured level is more accurate and is more resistant to process noise and obstructions in the tank. (ENDRESS & HAUSER, 2003d) (ENDRESS & HAUSER, 2004).

Figure 21 Tank 05 Micropilot M Radar Level Transmitter

3.2.5 **Weight Transmitter**

Tank 05 is also fitted with a load cell weight transmitter so that the level in the tank is inferred from the transmitted weight signal. The tank is mounted so that the full weight of the tank can be brought to bear on the load cell. The cell assembly is mounted on a stand under the tank with the tank mounted on a plate which concentrates the weight of the tank on the centre point of the plate. The plate can be lifted above the cell using jacking bolts for correct load cell location. The initial set up involved adjusting the cell course adjustment to touch the under-side of the plate then adjusting the jacking bolts to have the full weight of the tank on the cell. (BONGSHIN, 2005) (DATAFORTH CORPORATION, 1995-2009a) (DATAFORTH CORPORATION, 1995-2009b).

Figure 22 Tank 05 Weight Transducer

3.3 Flow Transmitters

3.3.1 **Electromagnetic Flow Meter**

Electromagnetic flow meters work on the principle of Faraday's law: that is, moving a conductor through a stationary magnetic field will produce a voltage proportional to the field strength and velocity of the conductor. The flow meter has no moving parts or intrusions into the pipe work, therefore there is nothing to wear out or produce a pressure drop in the pipe work. To apply Faraday's law the flow meter is constructed with coils on either side of a section of pipe (called the metering pipe). The coils (and cores) are arranged so that when a current is passed through them a magnetic field is produced which passes through the metering pipe. Measuring electrodes are installed into the pipe walls at 90 degrees to the magnetic field. These electrodes are insulated from the pipe and will only measure the voltages generated in the flowing liquid, as depicted in Figure 23. When a conducting fluid is passed through the metering pipe a voltage is produced at the electrodes whenever a current is passing through the magnetic coil circuit. The voltage is produced by the fluid passing through the magnetic field produced by the coils. The magnitude of the voltage is directly proportional to the velocity of the fluid. If the diameter of the metering coil is known and the field strength is also known, then velocity and hence flow of the liquid in the pipe can be precisely calculated. The flow meter does this calculation and outputs either a 4-20mA scaled current signal or a pulsed output based on volumetric units.

Factory calibration of flow meters is usually completed in the following manner. Rather than measure magnetic flux density produced by the coils, the flow meter is placed in a flow testing facility and a known flow passes through the meter. The excitation (current flow) of the coils is adjusted to produce a precise voltage response from the flow meter measuring electrodes. This excitation is recorded and stamped on the flow tube and is known as the K-Factor of the flow meter. It is required for the set up procedure of the flow meter. The excitation current through the coils is pulsed DC, to eliminate electrolysis on the measuring electrodes.

Electromagnetic flow meters usually comprise two components, the magnetic flow tube assembly and the flow meter converter. The converters are usually adaptable to many models of flow tube. They control the excitation current, do all flow calculations and scaling and provide transmission to the control system.

$e = B \cdot L \cdot v$

$Q = A \cdot v$

Ue_ induced voltage

B_ magnetic induction (magnetic field)

L_ electrode gap

V_ flow velocity

Q_ volume flow

A_ pipe cross-section

I_ current strength

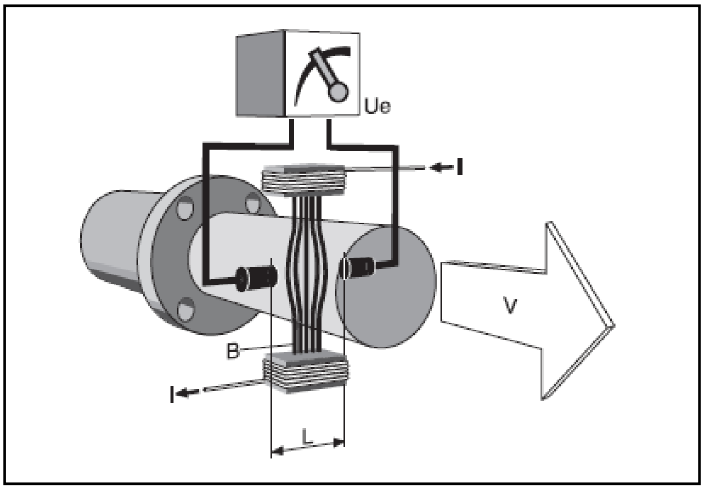

Figure 23 Promag operating principal. (ENDRESS & HAUSER, 2006a)

Figure 24 Promag M Magnetic Flow Meter FIT02

Figure 25 Promag W Magnetic Flow Meter FIT07

Two types of electromagnetic flow meters are installed in the Ultimate Water System. They are a Promag 10 converter with Promag M flow tube and a Promag 10 converter with a Promag W flow tube, refer to Figures 24 and 25. The converters and flow tubes are an integral unit, not separable. The primary difference between the two types of flow meters is that the Promag W is a flanged flow meter with 1 ½ inch ANSI 150 flanges and the Promag H has 1/2" NPT process connections. (ENDRESS & HAUSER, 2005) (ENDRESS & HAUSER, 2006b) (ENDRESS & HAUSER, 2006a)

3.3.2 **Vortex Shedder Flow Meter**

Vortex Flow meters work on capturing the effect of a fluid dynamics phenomenon termed the Karmen Vortex Street. The term refers to an effect caused by fluid passing by a bluff body. As the fluid passes, a repeating pattern of swirling vortices is created by the separation of the fluid to pass around the body, such as the singing of power lines or the flapping of a flag in the wind. As with the magnetic flow meter a vortex flow meter has no moving parts however it has a protrusion in the form of a vortex shedder which passes through the diameter of the pipe, this will result in some pressure drop and possible fouling. The design of the vortex shedder in the instrument is basically a wedge shaped shaft passing through the diameter of the pipe with the sharp end facing up stream into the flow, (refer to Figure 26). Fluid flowing in the pipe passes the leading edge of the wedge causing vortices to be created. The vortices travel down the pipe carried along by the liquid flow. Pressure changes between the vortex and the liquid act on the back area of the wedge causing it to flex as the vortices pass. Capacitance sensors in the wedge sense the flexing of the shaft which the transmitter counts, with each flexing of the wedge representing one vortex. An internal algorithm uses the count rate from the sensors to produce a scalar 4-20mA output. Vortex flow meters are extremely useful in flow measurement situations where conductivity is very low or when the fluid is a gas (ENDRESS & HAUSER, 2005).

Factory calibration of the vortex flow meter is very similar to that of the electromagnetic flow meter. The transmitter is flow tested and the testing returns a K-factor which is entered into the transmitter. The K-factor accounts for any geometric differences in the vortex shedder or pipe diameter which may affect calibration.

$$\text{K-factor} = \text{Pulses/unit volume } (dm^3)$$

Flow meter FIT06 is a Prowhirl 72F Vortex shedding flow meter as shown in Figure 27.

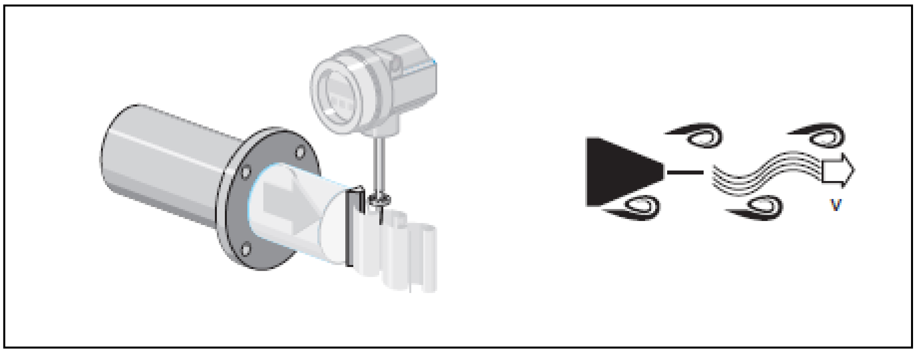

Figure 26 Prowhirl operating principal (ENDRESS & HAUSER, 2004)

Figure 27 Prowhirl Vortex Shedder Flow Meter FIT06

3.3.3 **Positive Displacement Flow Meter**

Flow meters FT03 and FT05 are McNaught M10 positive displacement flow meters. The McNaught M10 flow meter is a geared oval flow meter and works as depicted in Figure 28. Fluid flowing into the flow meter force the rotors to turn, each revolution of the rotor delivers a metered volume of fluid to the outlet. Magnets are installed in the rotors and activate reed switches as the rotors rotate. The output of the flow meter is the pulsed signal from the operation of the reed switch contacts. The flow meters are fitted with two sets, of contacts (one set per rotor), each of which meter flow at 36 pulses per litre, they can be set for dual operation which returns 72 pulses per litre of water flowing through the meter.

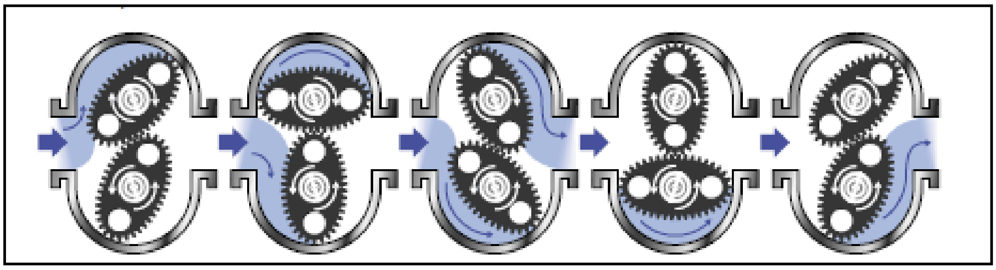

Figure 28 McNaught M10 Flow Meter Flow Schematic (McNaught, 1998)

McNaught flow meters are fitted with moving parts which have close tolerances. Therefore, unlike the other installed flow meters, these will cause higher pressure loss in the process and may be prone to failure due to fouling of the rotors.

Positive displacement flow meters such as the McNaught have limitations in their use however they offer a very accurate, cost competitive alternative to some of the other electronic flow meters on the market.

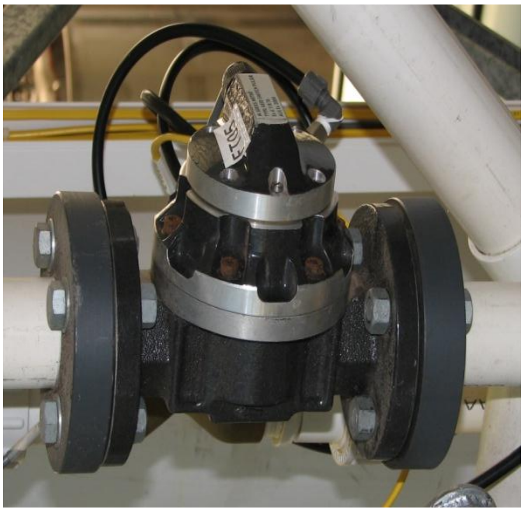

Figure 29 McNaught M10 Geared Flow Meter FT05

3.4 SEW Variable Speed Drives

The SEW variable speed drive is an electrical device used to control the speed of rotation of an electric motor. The speed can be remotely controlled via a control signal or locally controlled via a manual speed adjustment. These drives are supplied by a single phase 240VAC power supply and deliver 3 phase 415VAC output to the motor. The VSD rectifies the single phase supply, steps up the voltage then reconstructs it into a 3 phase supply via an inverter in the VSD. The voltage and frequency of the reconstructed 3 phase output is scaled to the 4-20mA speed control signal. Pump motor power and speed parameters are configured into the VSD. These parameters are used to protect the motor from failure due to overload or over speed. Motor speed ramp up and ramp down functions are configurable to protect driven equipment. The VSD has PI process control capability built into the inverter unit.

Figure 30 UWS SEW Variable Speed Drives

VSD's are used extensively in industry to drive motors which control flows in particularly harsh process conditions. Controlling the speed of the pump has many advantages over control valves when controlling flow, such as reduced energy consumption caused by using only the energy required to attain the correct flow, reduced pressure drop by removal of the control valve, and reduced pump cavitation which leads to increased pump life.

VSD's installed in the Ultimate Water System, (refer to Figure 30), are all configured similarly. The major parameters are: Motor Speed 150 – 1500 RPM, Motor Power 0.97 kW, motor voltage 415VAC and speed set point signal 4 – 20mA. The VSDs have extensive self diagnostic capability. Alarm access and codes are available in the user's manual. (SEW EURODRIVE, 2004) (SEW EURODRIVE, 2003).

3.5 HART Protocol

The Acronym HART stands for Highway Addressable Remote Transducer Protocol. The flow meters and level transmitters installed in the Ultimate Water System all have HART capability. HART is a communications protocol developed to operate over the 4-20mA transmission signal. The system operates using frequency shift keying (FSK): 1200Hz represents logic 0 and 2200Hz represents logic 1. The signals for 0’s and 1’s are superimposed on the DC signal in sine waves so that analogue and digital transmission are taking place simultaneously. Because the average of the FSK signal is zero the DC signal is not affected.

The system operates as a master slave system. In a control system operating totally in HART mode, the master would be the Distributed Control System. In the case of the Ultimate Water System, the master is the FLUKE Calibrator (FLUKE CORPORATION, 1998).

The benefit of HART communication is that information other than the 4-20mA signal can be transmitted back and forth between the field instrument and the control system. This allows remote instrument interrogation and condition monitoring. HART communications has encouraged instrument suppliers to develop intelligent transmitters and actuators with capabilities to detect faults and report on the condition of the driven device and environment. 238 instrument suppliers currently have 990 different devices available in the market with HART capability.

Digital control networks such as Fieldbus and Profibus are becoming common place in industry. However HART transmitters and actuators are often installed into older 4-20mA control systems. In these older systems a device called a splitter is installed in the current loop to separate the HART information from the transmitted signal. The splitter delivers the information digitally to a PC or control system for processing. (HART COMMUNICATION FOUNDATION, 2009)

3.6 Control Valves

Valves FV01 to 03 are Baumann (Fisher) 5100 Series control valves and FV04 is a Fisher 32.24688 control valve. These valves are all pneumatic diaphragm actuated with spring return. The flow controlling valve arrangement in these valves is known as a globe valve. Their action is direct, which means that an increasing control signal will increase flow through the valve. The valves are fail safe closed, meaning that if the air supply fails or the instrument signal is lost the valve will close, stopping the flow. Selecting the correct size and characteristic of the control valve is vital to achieve effective control. (Fisher, 2005)

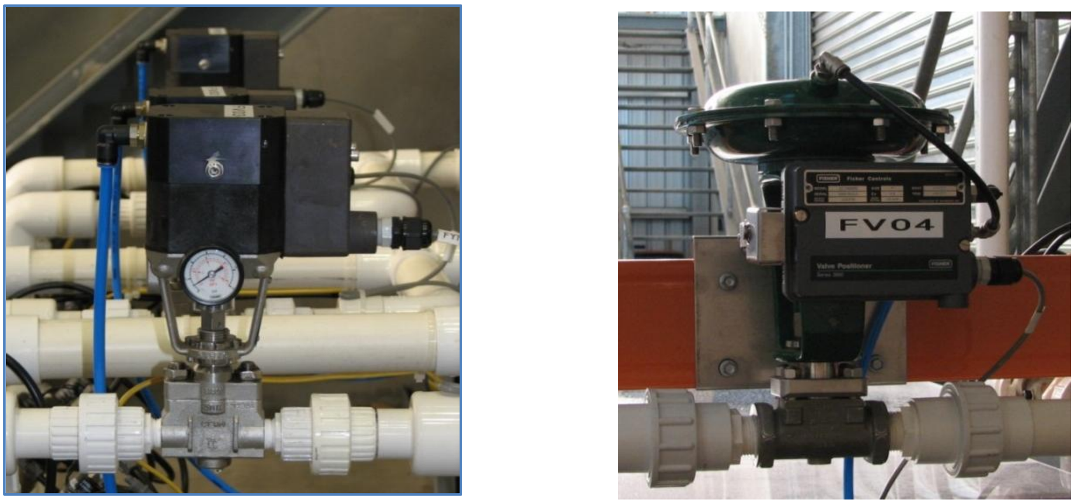

Figure 31 Control Valves FV03 and FV04 installed in the UWS.

4 UWS Commissioning

It is common practice to document commissioning difficulties and findings encountered in a project for future reference. The following are findings relating to the commissioning of instruments and electrical equipment on the Ultimate Water System. The commissioning of the system was conducted in 3 parts, each part is explained below.

Pre-commissioning: No power was applied during the Pre-commissioning checks. A thorough check of the Ultimate Water System instrumentation and electrical installation was conducted. This check was conducted towards the end of the works required for the project. A spreadsheet was prepared containing all instruments and electrical equipment items to be installed. For each item a list of requirements was compiled. The list was then used as a tick-list to be sure all requirements for the installation were complete and any shortfalls were noted and completed.

Dry–commissioning: At this point power was applied to the power and control panel. Electrical safety checks were completed on all powered components before the power was applied. As the term suggests, dry commissioning is completed before process fluid is added to the system. The instrument 24VDC power supply was turned on and checked for operation. Level transmitters were powered on and checked for operation and initial calibration figures were installed. Flow transmitters were powered on and initial flow calibration figures installed. Each transmitter was set for 100 litres per minute. Control valves were stroked. That is, the control input to the control valve changed from 0 to 100% and the operation of the valve checked by observing the movement of the valve stem. Initial set up of the Tank 05 weight transmitters was completed, ensuring the full weight of the tank was acting on the load cell. Solenoid valves were all turned on and off to ensure the valves were responding. This was completed by removing the air tubing from the side of the diaphragm acting to open the valve and the side of the diaphragm acting to close the valve and insuring air was being directed to modulate the valve as required by the control system. No external indication of valve position is available on these valves.

Wet commissioning: Wet commissioning is the final stage of commissioning and as the name suggests process fluid, in this case water was added to the system and the system run to determine if all components were functioning correctly. All of the pumps were bump tested, that is, the pump drive motor rapidly turned on and off to ensure correct rotation. This test was completed after water was added because the pump elements require water to be present whenever the pumps are rotated. The correct ranges for the flow meters were then resolved because it was possible to run the pumps at full speed and determine maximum flows in the system. Final calibration of the tank level transmitters were then completed because setting the transmitters with water in the tanks allowed for more accurate tank empty and tank full range determination. Control valves were checked for operation and hysteresis. Solenoid valves were also checked for operation.

4.1 LabVIEW Commissioning Programs

The commissioning process required basic LabVIEW programs to prove the operation and calibration of the instruments. The content in each of the programs was based on commissioning similar types of inputs or outputs, as suggested by the titles:

Test Module 1DI
Test Module 2 3 DO
Test Module 4 AI
Test Module 5 6 7 AI
Test Module 8 DI

The program operator interface and block diagram for one of the test programs are displayed in Figures 32 and 33 and the remaining programs are available in Appendix C.

The commissioning programs as previously stated, are very basic, Figure 32 displays the Digital Input Module 1 commissioning HMI. As can be seen, the display comprises 19 ON/OFF indications. These are connected directly to the module inputs in the CompactRIO as shown in Figure 33.

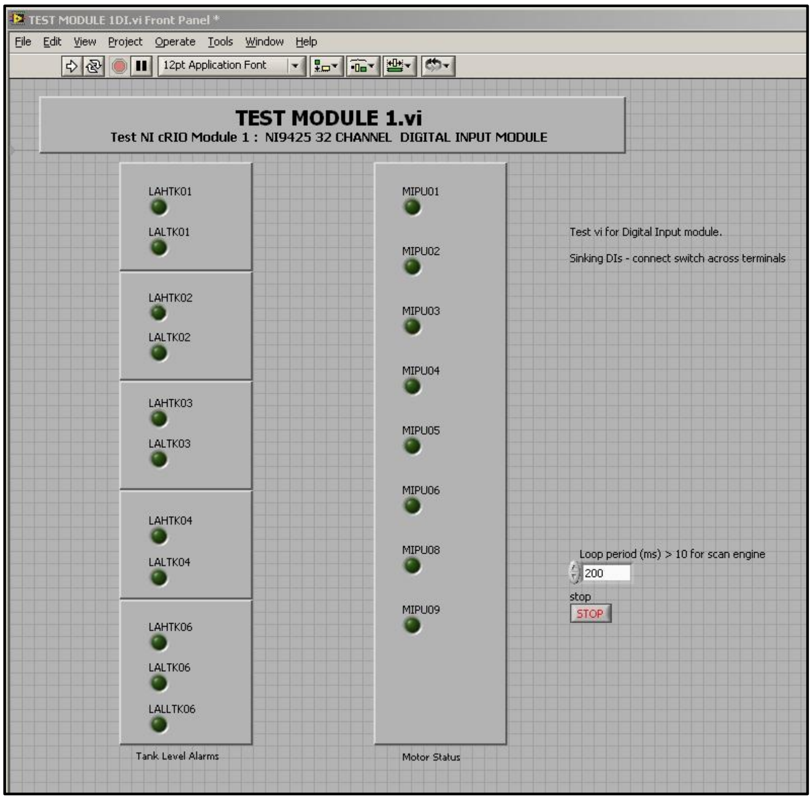

Figure 32 Module 1 LabVIEW Test VI

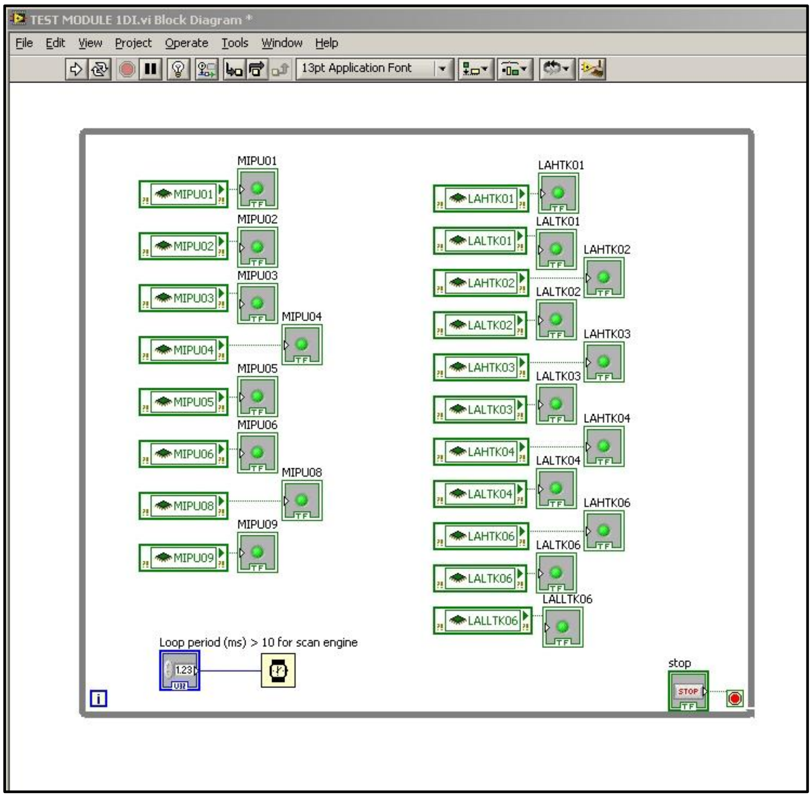

Figure 33 Module 1 LabVIEW Test VI Block Diagram

4.2 Tank 01 and Tank 02 Level Transmitters

The transmitters on tanks 01 and 02 were mounted below the tanks because in a liquid level measuring service any air trapped in the impulse tube will cause errors in the measured pressure. Mounting the transmitter below the tapping point will ensure any trapped air will leave the impulse tube and vent into the tank.

Initial dry calibration of the pressure level transmitters was done by measuring the distance from the transmitter to the bottom of the outflow pipe to give the pressure exerted on the transmitter at zero tank level (ENDRESS & HAUSER, 2003b). The zero measurement plus the measurement from the bottom of the outflow to the bottom of the overflow is the 100% level.

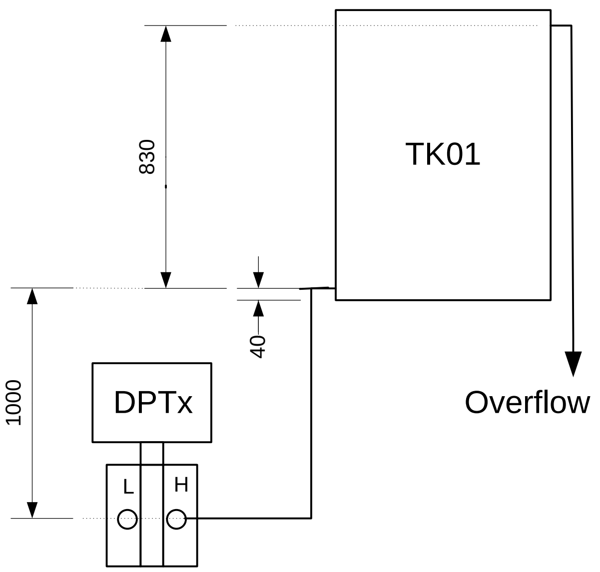

Figure 34 Tank 01 Level Transmitter Dry Calibration

Tank 01

Zero = 1000 mm water

100% = 1000 + 830

= 1830 mm water

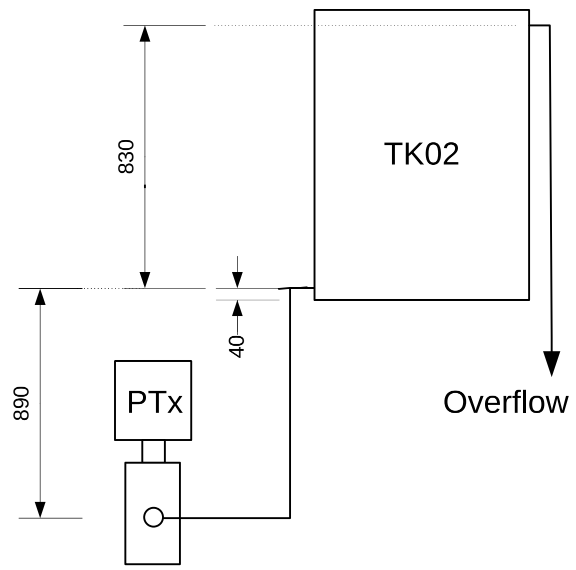

Figure 35 Tank 02 Level Transmitter Dry Calibration

Tank 02

Zero = 890 mm water

100% = 890 + 830

= 1720 mm water

The final calibration of these transmitters was done with water in the tanks (wet calibration). The tanks were filled to 100% level (overflow) then 0 % level (drained until empty). At each extreme the transmitter was used to measure the pressure head in mm of water. Each transmitter was then set to measure between the noted pressures, which they were as follows:

Tank 01	0% level:	999 mm H_2O
	100% level:	1830 mm H_2O
Tank 02	0% level:	897 mm H_2O
	100% level:	1722 mm H_2O

4.3 Tank 03 Level Transmitter

The Liquicap capacitance level transmitter was calibrated using the transmitter's integral display. The basic set up was interrogated and the factory sets left unchanged. The tank was emptied and while in the basic set up menu, wet operating mode the tank empty calibration was performed. The tank was then filled with water to the overflow and the tank full calibration was performed. The tank was then emptied and filled to check calibration was complete. For full details on these functions refer to the Liquicap M Operating Instructions. (ENDRESS & HAUSER, 2003c)

4.4 Tank 04 Level Transmitter

Tank 04 is fitted with a Prosonic FMU40 ultrasonic level transmitter. This transmitter is calibrated in much the same way as the Liquicap transmitter. The calibration is done using the transmitter's local display or the HART communicator. In this case a wet calibration was performed. The local display was set for Basic Setup – dist.meas.value. The tank was then filled and emptied and the indicated distance values recorded for a full and empty tank. These values were then entered into the Basic Setup, Empty Calibration and Full Calibration parameters. The tank was then filled in 25% increments and the actual level compared with the indicated level from the transmitter. The indication correlation was extremely close. The transmitter has built in capability to eliminate false echoes caused by obstacles in the tank. This function was not required and was turned off. (ENDRESS & HAUSER, 2005)

4.5 Tank 05 Level Transmitters

The weight transmitter comprises 3 separate components - a PUT 5 volt power supply (PUTPOWERTECH INC), a Dataforth Strain Gauge Input Module and Analogue I/O Back Panel (DATAFORTH CORPORATION, 1995-2009a; DATAFORTH CORPORATION, 1995-2009b) and a Bongshin Load Cell (BONGSHIN, 2005). The output from the load cell circuitry was scaled to indicate tank level. The scaling was done in the NI 9205 analogue input module via LabVIEW. The level indication was calibrated by recording the tank full and tank empty load cell outputs. Tank empty output was 0.8 volts and tank full output was 3.33 volts. The tank was then filled in 25% increments and the level indication checked: the correlation was excellent. Refer to Figure 36 for LabVIEW calibration.

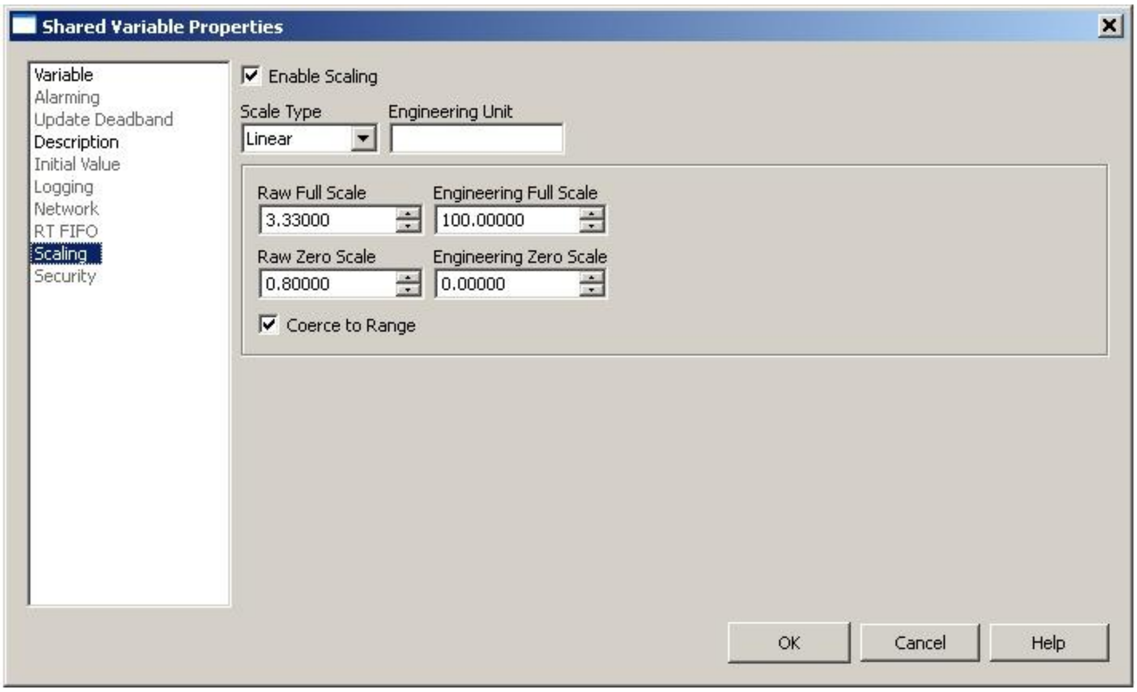

Figure 36 LabVIEW calibration Tank 05 Level Transmitter

4.6 Control Valves

Control valves FV01-03 are Baumann (Fisher) 5100 Series valves and FV04 is a Fisher 32.24688 control valve. Initial testing of control valves involves checking the stroke of the control valves stem (and trim) for correct opening pressure. That is, the pressure at which the control valve begins to open and the pressure at which the control valve is fully open. Control valves FV01 – FV03 have no adjustment other than the spring tension and valve trim position. The calibration of these are done by the manufacturer: this calibration is termed bench setting the valve. FV04 has a more expensive valve positioner, which has span and zero adjustments, as can be seen in Figure 43.

The valves were stroked to test their response. The stroking was done by connecting a current source to the valve positioners and simulating inputs to attain valve position. The position has to be attained with input current rising and then falling to reveal any hysteresis. This proved to be tedious and difficult because of the very small stroke of the control valves. In order to acquire the data the input currents to attain valve positions of 0, 50 and 100 % were recorded. The charts reveal valve FV04 has far superior performance. Valves FV01-3 performance may be hindered because of sticking, (jamming) of the valve trim - all 3 have similar problems. Valve stroke testing results for FV01, FV03 and FV04 are shown in Figures 37, 38 and 39.

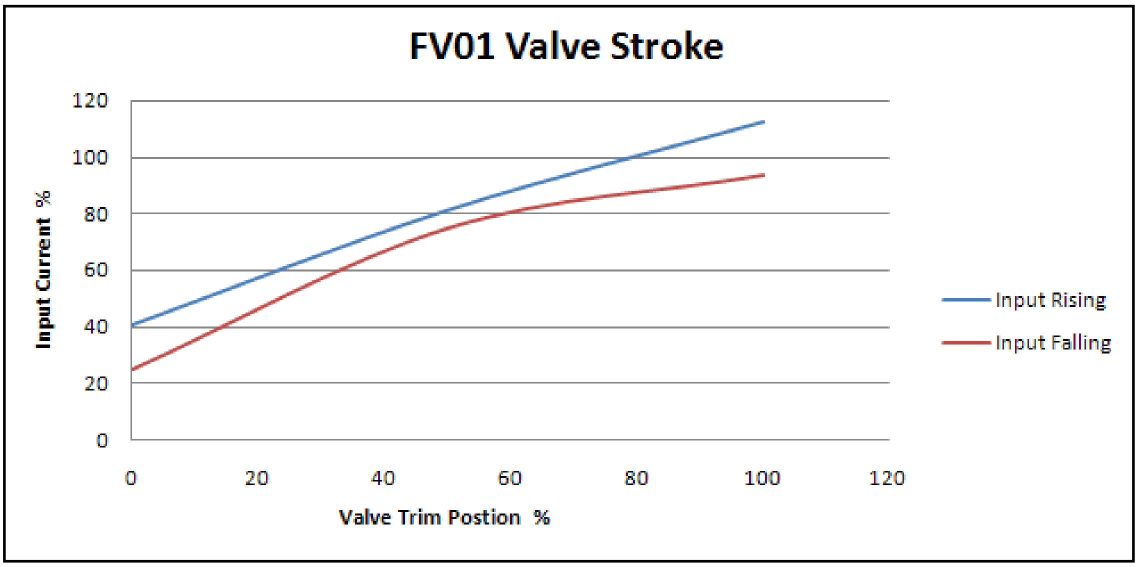

Figure 37 FV01 Valve Stroke Result Chart

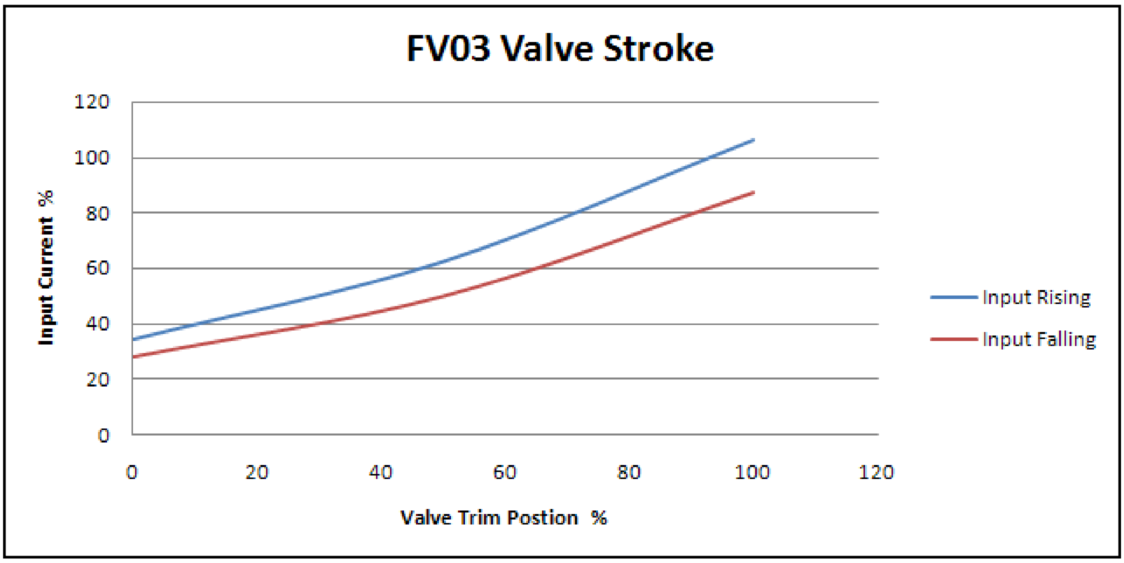

Figure 38 FV03 Valve Stroke Result Chart

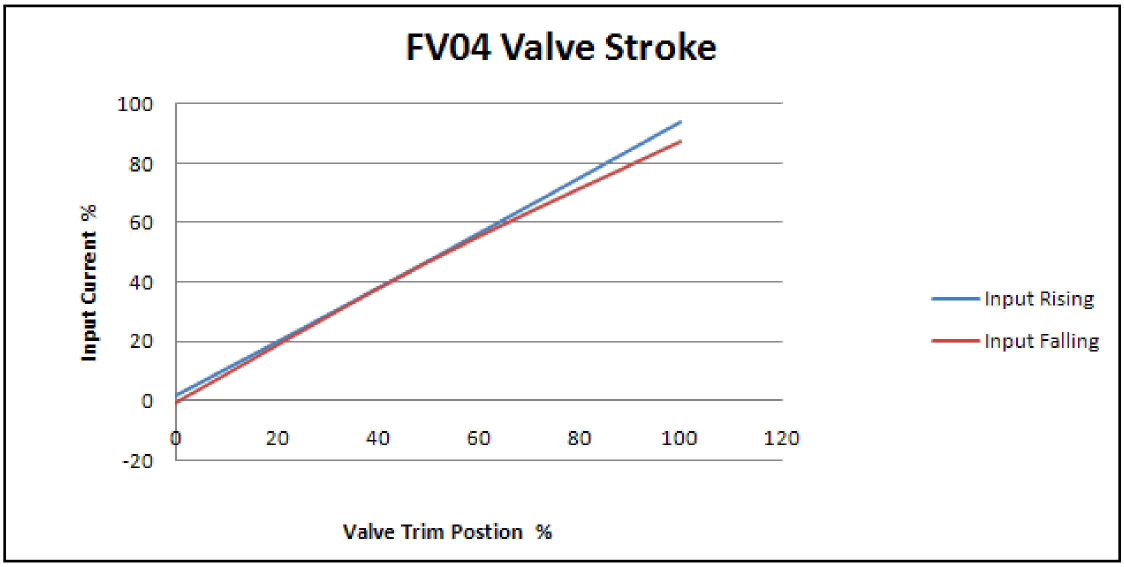

Figure 39 FV04 Valve Stroke Result Chart

Stroke tests of the control valves suggested poor performance so it was decided to test the performance of the valve input with respect to water flow. This check was primarily focused on revealing calibration and hysteresis errors. Calibration errors such as the point where flow is completely stopped and where it reaches a theoretical 100% are revealed. Hysteresis problems refer to the valves ability to repeat a particular flow regardless of whether the signal is rising or falling. (Borden Guy Jr and Friedman Paul G, 1998) (Fisher, 2005)

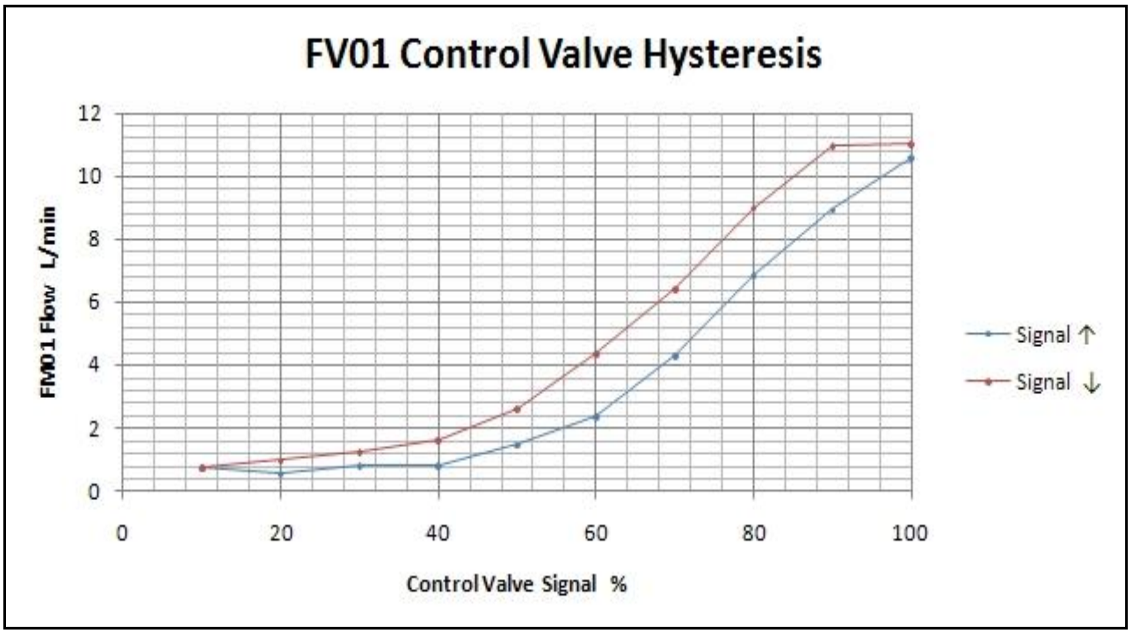

Figure 40 FV01 control valve hysteresis

The Control Valve Hysteresis results (Figures 40– 42) reveal that control valves FV01 – FV03 all suffer from minor calibration errors but have major hysteresis problems. Hysteresis becomes a problem when the control valves are in service. For example in the case of FV02, the valve can move up to 20% with no effect on the flow through the valve as shown in Figure 40. The response of FV04 (Figure 43) is a great improvement - the valve positioner on this valve is more sophisticated, hence the improvement in performance.

Figure 44 is typical of the response from a variable speed drive and pump combination. There is virtually no hysteresis and the flow characteristic is linear. The variable speed drive has a minimum speed of 10% or 150 RPM. This is because the fan cooling the motor is attached to the motor drive shaft - the shaft must be kept turning to move some air over the cooling fins of the motor or else eventually the motor will fail.

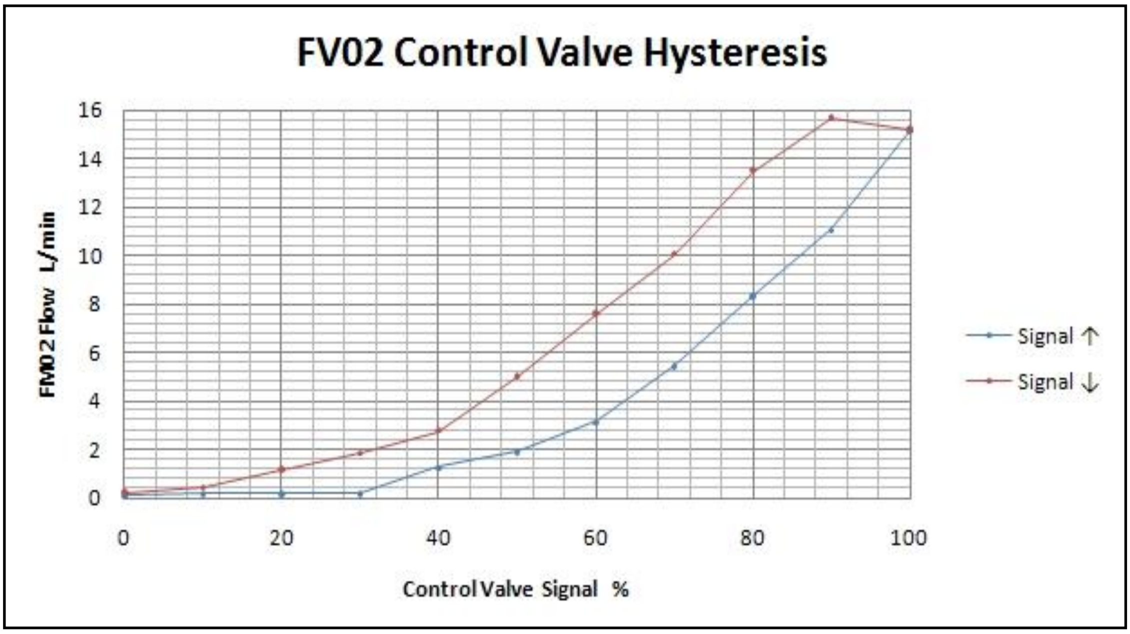

Figure 41 FV02 control valve hysteresis

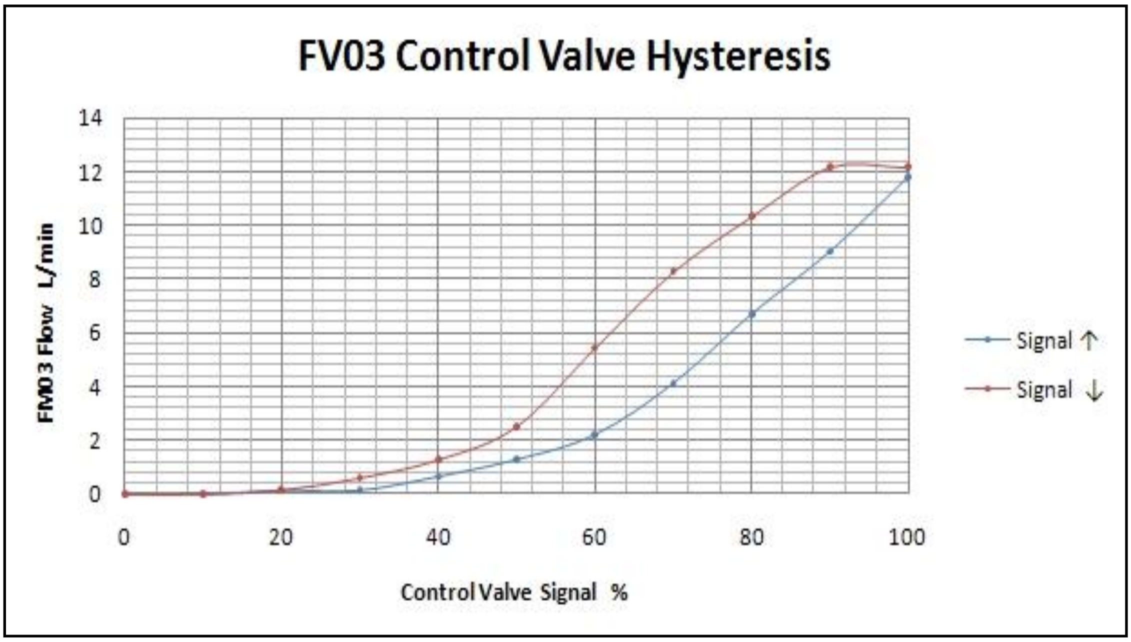

Figure 42 FV03 control valve hysteresis

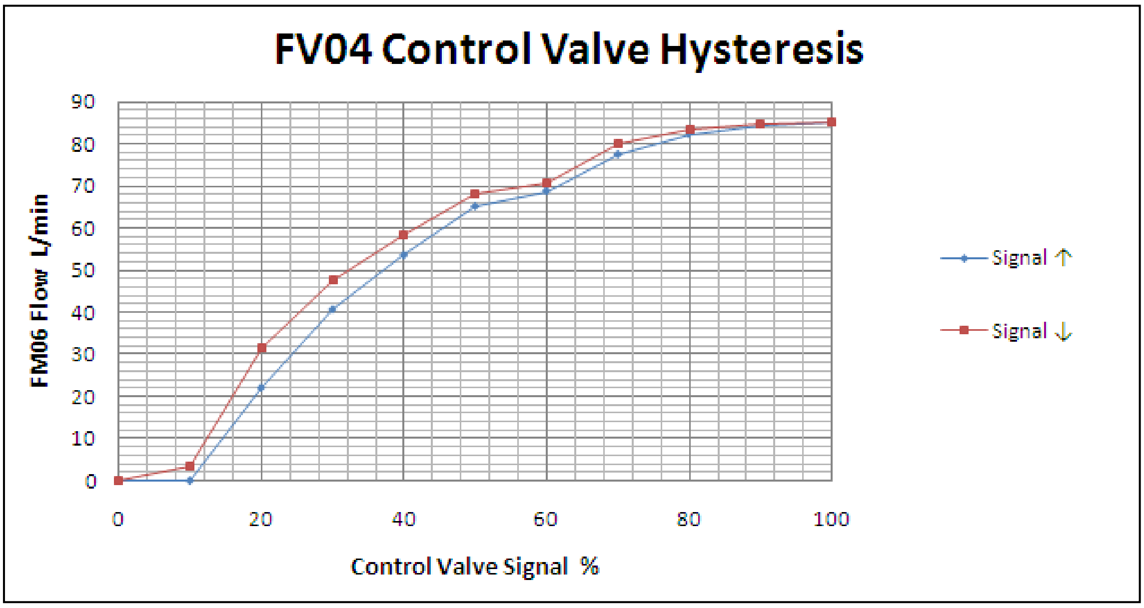

Figure 43 FV04 control valve hysteresis

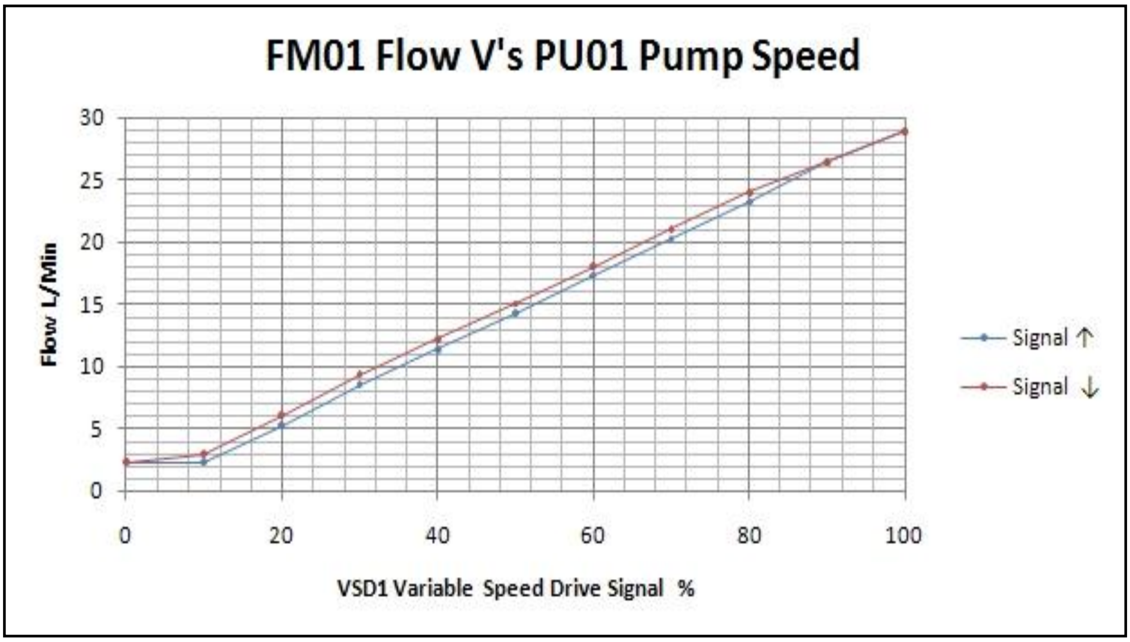

Figure 44 Pump 1 / Variable Speed Drive 1 hysteresis

4.7 Tank 05 Level Transmitter Comparison

Tank 05 was fitted with a weight transmitter, calibrated to return level indication, and a radar level transmitter. The weight transmitter was set up to measure level by filling and emptying the tank and adjusting the LabVIEW input conditioning to suit the level in the tank at 0 and 100%. The radar transmitter was calibrated in much the same manner, however the adjustments were via the transmitter's integral human machine interface. A test was conducted to compare the performance of the radar level transmitter and the weight level transmitter. The results are displayed in Figure 45, LIT05 is the signal from the radar level transmitter and WITK05 is the signal from the weight/level transmitter.

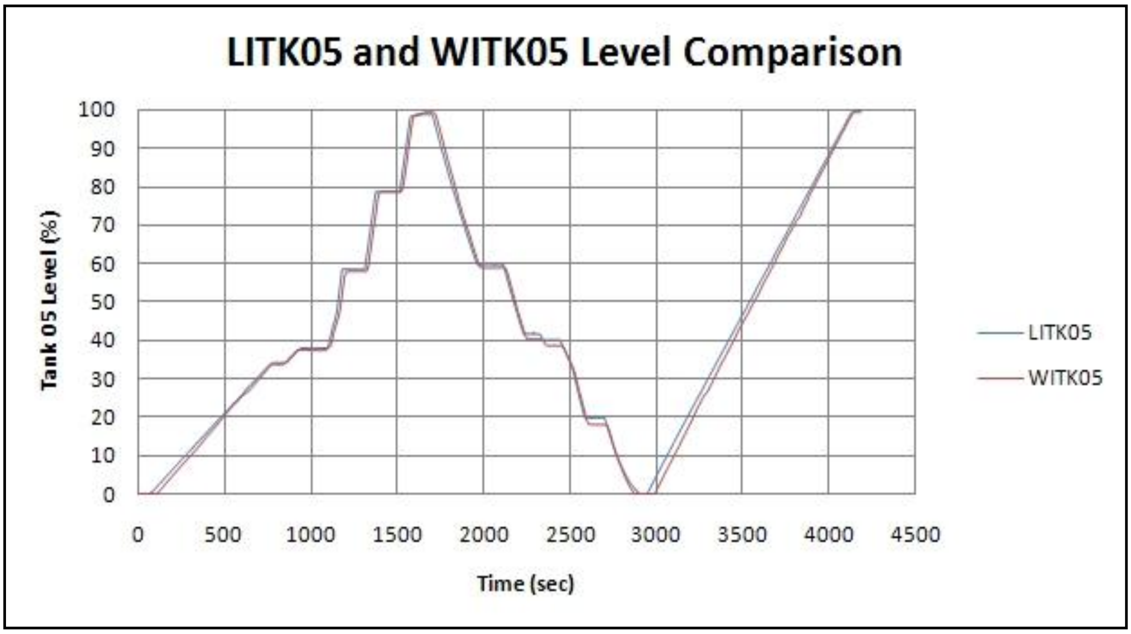

Figure 45 Tank 05 Level Transmitter Comparison

4.8 Commissioning Problems and Resolutions

The following is a brief list of problems encountered during the commissioning process:

a) Missing cables for tank 1 and 2 transmitters. The cables for level transmitters on Tanks 1 and 2 were not initially installed. These cables were installed after pre-commissioning.
b) Missing cables for weight the transmitter. The load cell was installed late in the project. This required the cable from the load cell to the control cabinet to be joined and lengthened. The joints in the cable were soldered to reduce the possibility of including additional resistance in the load cell circuit. The installation of the load cell was hindered by incorrect placement of the frame under the tank: the frame was relocated and the problem resolved.
c) Sticking control valves. Control valves FV01, FV02 and FV03 all displayed sticking in the closed position. The valves were stripped down and cleaned, however the sticking occurred again on many occasions. The UWS is fitted with a filtering system and this was checked. It was determined that the flow through the filter was very

low and caused very little turbulence in the reservoir, therefore very little filtering was occurring. A replacement filter pump was sourced and installed into the system in an attempt to clean out debris in the process fluid. The replacement pump has significantly improved performance. The filter pump was initially powered as part of the control system, however it was re-wired to an external power supply to allow operation when the control system was not in use. In addition to the new filter pump a cover was installed over the reservoir to reduce debris falling into the tank and contaminating the process fluid.

d) Pump PU05 seized. PU05 was found to be seized. Before this occurred the pump was running in reverse. This could have caused the impeller to unscrew from the shaft and seize the pump. Repairs were completed and the pump put into operation. VVVF settings were found to be correct. The pump was vibrating but otherwise pumping very well.

e) Pumps running in reverse. All pumps except PU09 required reversing. This was rectified by interchanging the connection of two of the phases supplying power to the pump motor, these changes were completed during wet commissioning.

f) VVVF control problems. Wet commissioning revealed that the design for the control of the SEW variable speed drives was faulty. The original design used the National Instruments current sinking digital output to switch control voltage to the SEW variable speed drive enable and clock wise rotation inputs. The correct design required voltage free contacts to switch an internal variable speed drive 24 volt control signal to these terminals. The wiring was changed to incorporate relays 14 -19 (originally installed for future lighting) to do the switching via NI Digital Output Module 2. Refer to drawing UWS 0004 CompactRIO Module 2. NI9478 16 Channel D.O. These changes solved the problem in all SEW VSD’s.

g) Power supply problems. The initial powering up of the Ultimate Water System control panel resulted in repeated tripping of the residual earth leakage devices in the main power supply. Investigation revealed that the tripping occurred when the 24VDC power supplies were energised. The 24VDC power supplies are switching power supplies and have a leakage path to earth in their design. (MEANWELL) This problem was rectified by the university Technical staff.

h) Compressed air pressure problems with valves and diaphragm pump PU07. Wet commissioning revealed that the diaphragm pump would not operate with pressure below 200kPa and the solenoid valves would not operate reliably with pressure above 150kPa. These devices were supplied from a common air supply and pressure regulator. This problem was eliminated by installing a separate air supply and regulator for the diaphragm pump.

i) Installation of too many cables to solenoid valves. Initially two cables were installed to every solenoid valve - it was later revealed that the actual requirement was in fact one per valve. The additional cables were used for the tank high and low level switches. These switches were not in the initial scope of the project, however they were installed and commissioned.

j) Burnt out fuses. The magnetic flow meter power supply fuses, fuse 20 to fuse 24, rated at 100mA, were found to be failing. These fuses were changed to 500mA fuses and the problem was eliminated. The problem was caused by high inrush current from the transmitters exceeding the fuse's rated capacity.

k) Burnt out solenoid valve coils. SV17 was found to be inoperative during wet commissioning. Investigation revealed both solenoid coils to be open circuit. These were replaced with new coils which eliminated the fault.

l) Solenoid valve intermittent operation. Solenoid valves show signs of intermittent operation. Investigation revealed that this problem only appeared if the solenoid coils were energised for long periods. It is suspected that the intermittent operation may be caused by the heating of the coils and valve assemblies. Because of the intermittent nature of the fault, the actual cause could not be isolated.

m) Flow meter accuracy problems. During the wet commissioning of the flow meters it was noted the flow meter local indications were double the indication on LabVIEW. Investigation revealed that the LabVIEW point configuration was set up for single ended inputs when in fact the connection was for differential input measurement. The configuration was changed to differential input measurement which eliminated the problem.

n) Terminal short circuit problems. Dry commissioning revealed powering up of the 24V DC power supply (PS1) resulted in continual tripping of the circuit breaker CB11 supplying 240VAC to the 24 volt power supply. Checks to the power supply revealed that a short circuit was present at the output of the 24V power supply. After investigation the fault was traced to the terminals mounted in terminal block TB05. Some of the terminals had been mounted incorrectly causing the internal metal parts of some terminals to come into contact with their neighbouring terminal's internal metal parts. Incorrectly mounted terminals were re-mounted correctly and the problem was resolved.

o) Low flow through the control valves; Wet commissioning revealed very poor flow capabilities from pumps PU02, PU04 and PU06. Investigation revealed that the Cv of the control valves installed is too small for the required flow. Refer to Recommendations For Future Work, Section 8.3.

p) Weight transmitter intermittent operation. Wet commissioning revealed very erratic Tank TK05 level indication. The level of Tank 05 is inferred from the installed load cell measuring the entire weight of the tank. The load cell was removed and re-installed several times to ensure the tank was exerting even pressure on the cell. However, no improvement resulted. A broken wire was later located in the cables at the control panel input terminals. The cable was re-terminated and the problem resolved.

q) Poor control on tank drain valves. Attempts to set up a simple level controller for Tank 03 were hindered because the tank drain flow modulating valve is a brass gate valve. The valve is very hard to set to a consistent flow low enough to allow a controller to operate. If the installed valves were needle valves then discharge flow would be much easier to control. The level control operation was moved to Tank 05 which has a flow control valve installed in the tank discharge. This resulted in the discharge flow being much easier to control and the implementation of a control system made possible.

r) McNaught Flow meters failing due to sediment in the water flow. The flow meters had to be stripped down on occasions because the internal gears had been fouled to a point where they would not turn. The filter fitted to the UWS was turned on however sediment visible in the tanks did not appear to be reducing.

5 Thesis Problem Resolution

5.1 CompactRIO Controller Installation.

The CompactRIO controller interface module layout and operation are different from the original Real Time Controller (National Instruments, 2010a) (National Instruments, 2010b). The layout of the CompactRIO modules are designed for much higher density inputs and outputs. Therefore changing from the Real Time controller to the CompactRIO required several modifications including;

a) Redirecting the control cabinet cables to reach their new destinations, because a lot more control cables were directed to a smaller area, causing overloading of the cable duct installed in the panel.
b) Terminating the control cables to the National Instruments Field Termination panels because the cross sectional area of the cables was at the upper limit for the terminals.
c) Connecting the large numbers of cables to the high density terminal assemblies and installing cable numbers (Tags) to the cables so that they were visible and the installation was neat and tidy.

5.2 Cable Numbering

The cable tag naming convention adopted in the original wiring of the Ultimate Water System involved naming the cable with the terminal it was attached to therefore each cable has two tag numbers attached which were different at both ends. This convention is only acceptable if there are no changes required in the panel wiring and if a drawing of the panel wiring is always available whenever fault finding is required. In the case of this particular thesis, extensive changes to panel wiring were required to fit the CompactRIO in place of the Field-Point Real Time controller.

Where possible this convention has been changed to a more manageable system. Each cable has a unique number, the same number at each end of the cable. This system allows for changes of wiring to be made without the need to change tags and crimp terminals (only a drawing change is required), and also makes fault finding without a wiring schematic diagram possible.

5.3 Engineering Drawings

The replacement of the Real Time Controller to CompactRIO resulted in the requirement to redraw the electrical and control drawings. It was decided to use Visio, a readily available, easy to use Microsoft package for developing drawings which require no scaling. All control drawings are presented in loop schematics with the key being the control system field termination module to which they are connected. The electrical schematic drawings are similar to the originals.

5.4 Tag Naming Convention

The instrument tag naming convention for the control system is adapted from the ISA standard ANSI/ISA-S5.1-1984 (ISA The Instrumentation,Systems and Automation Association, 1984). All instrumentation tags names for the UWS instruments were renamed.

5.5 Motor Isolator Status Indication

The original Ultimate Water System design was to have motor isolator status indications included in the control system and made available to the operator. The original design required that additional conductors in the power cables to the isolators be used to convey the presence of power at the output of the switch back to the control panel and interposing relays. The problem with the design is that power is only present when the control system calls the motor to run, which is true for PU02, PU04 and PU06. The remaining motors are speed controlled by VSD controllers which produce variable voltages and frequencies. The relays are designed to operate at 50Hz / 240VAC therefore they will not operate reliably to indicate motor run. This functionality was removed from the control system and a recommendation to reinstall them has been made, Refer to Section 8.8.

5.6 McNaught Flow Meter

During the control testing, problems with the McNaught flow meters FT03 and FT05 began to occur (Refer to Figure 50 Tank 05 Cascade Control Test Results). FT05 was stripped down and the problem was found to be plastic filings from the pipe work (created during construction), that were lodged in the oval gears of the flow meter. See Figure 46 Fouled FT05 McNaught flow meter rotor which shows the lodged filings. The filings were removed and the flow meter returned to service.
Investigation into common installation practice concerning these types of flow meters revealed that fouling problems were common in dirty flow services and “in line” filters were normally fitted in pipe work before the meter (McNaught, 1998).

Flow meter FT03 was also investigated for intermittent operation. No positive problem could be identified, however pump PU05 was causing considerable vibration to the pipe work (and flow meter) at the time. The vibration could have been causing the reed switches in the flow meter to chatter or there may have been debris catching in the rotor gears as per FT05. Stripping the flow meter revealed no debris and the rotors were free to rotate.

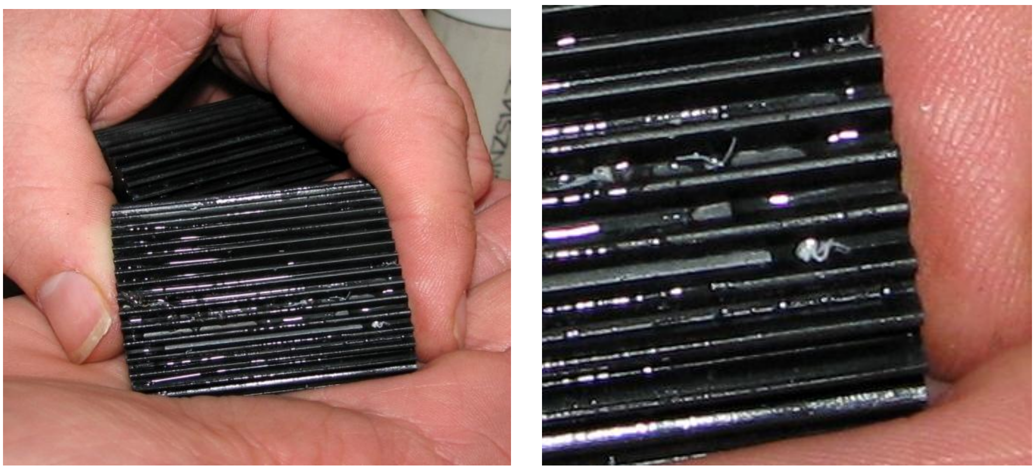

Figure 46 Fouled FT05 McNaught flow meter rotor.

6 Automatic Control Test

Cascade control tests were conducted on two separate tanks, 04 and 05. Automatic control tests were conducted using the LabVIEW interface developed by James Kurz. Conducting this exercise was a final test to prove the Ultimate Water System instrumentation installation was sound and suitable for control applications and for James' HMI.

6.1 Tank 04 cascade level control test

Cascade control was tested on Tank 04 by installing a level controller on the tank and cascading that controller onto a flow controller to modulate the flow of water into the tank. Referring to Figure 47 the primary loop of the system is the Level control loop and the secondary loop is the flow controller. The secondary loop in a cascade control system must have faster dynamics than the primary loop, illustrated in the control parameters below. Cascade loops such as this one reduce problems caused by valve hysteresis and calibration problems and can be used to reduce effects such as water hammer. These improvements are possible because the secondary controlled variable is a flow and it's control is independent of valve hysteresis (Liptak B. G., 2006). The tank level control is slightly under-damped, however the return to set point is rapid (Ogunnaike B. A. and Ray W. H., 1994).

Control Parameters

LCTK04		**FCFM02**	
Gain	*8*	Gain	*2*
Integral	*1*	Integral	*0.1*

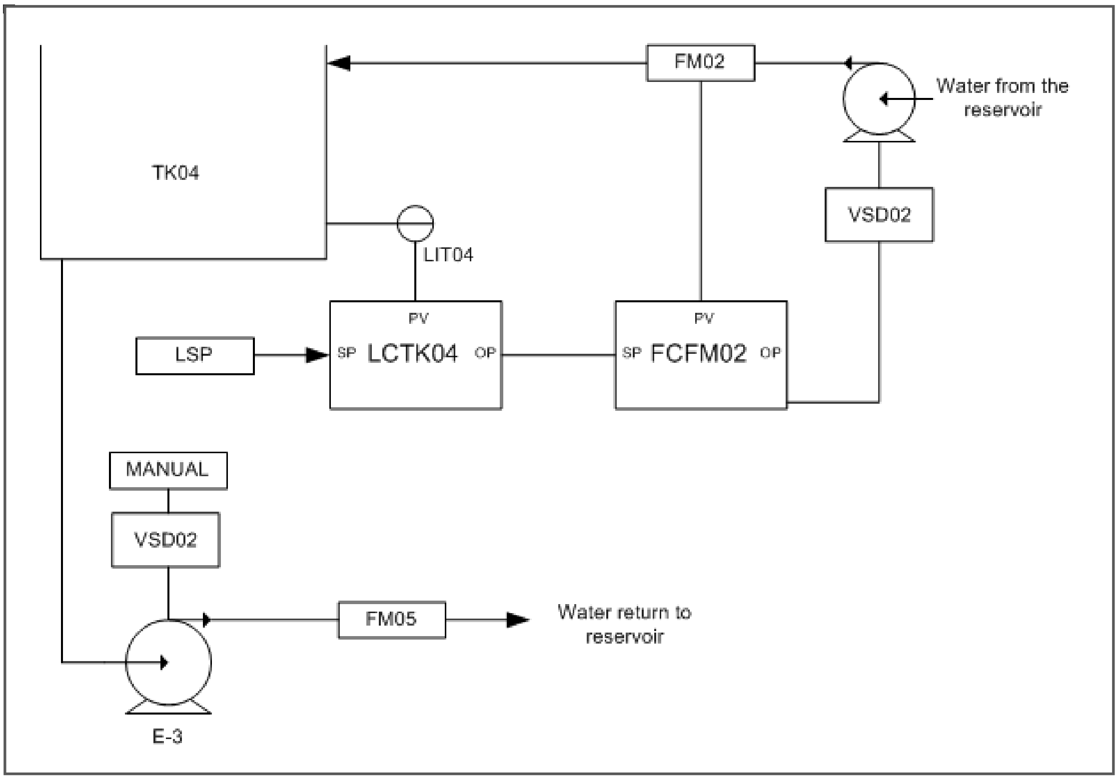

Figure 47 Tank 04 Cascade Control Test Schematic

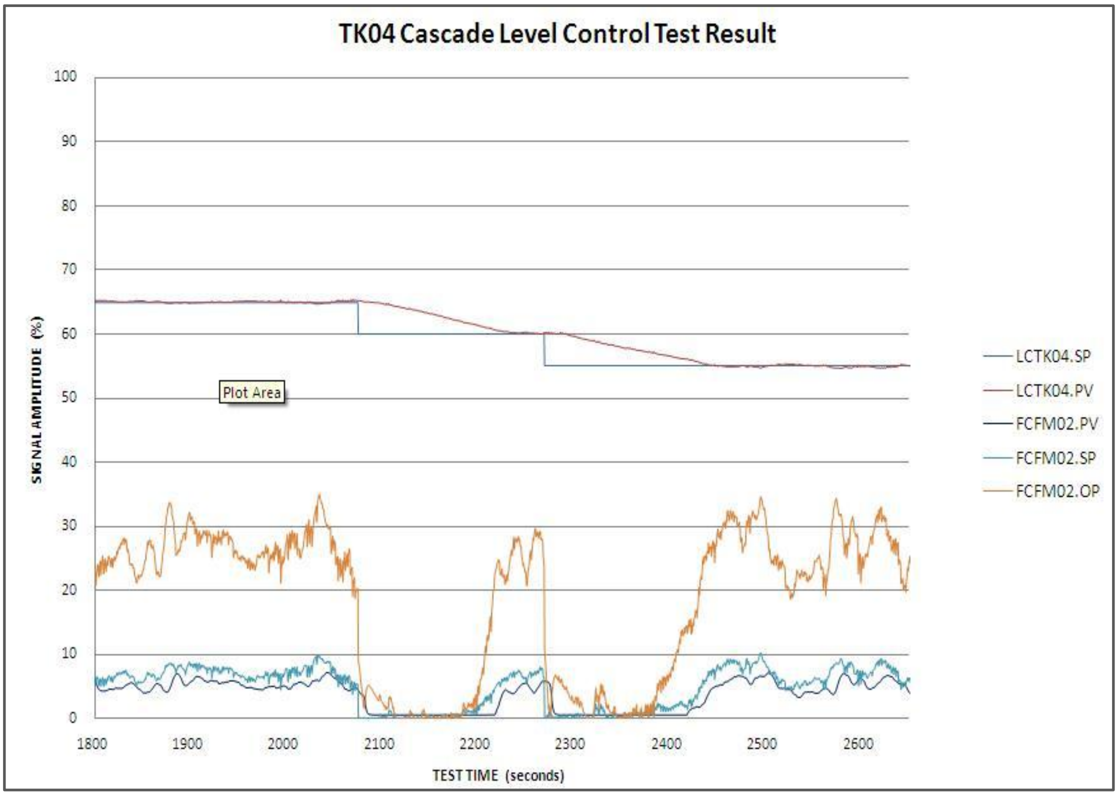

Figure 48 Tank 04 Cascade Control Test Results

6.2 Tank 05 cascade level control test

Tank 05 level control as shown in Figure 49 was installed as per Tank 04, the primary control loop was the level control and the secondary loop was control of the flow of water into the tank. As can been seen from Figure 50 the flow in FM03, a McNaught flow meter, displayed erratic operation. This was due in part to fouling of the flow meter internal gears and possibly to vibration caused by the pump. The vibration can cause the reed switch flow contacts to chatter. Tank level control was still very good regardless of the flow meter problems. The control was slightly under-damped but returned to set point rapidly.

Control Parameters

LCTK05		**FCFM03**	
Gain	*5*	Gain	*0.5*
Integral	*1*	Integral	*0.1*

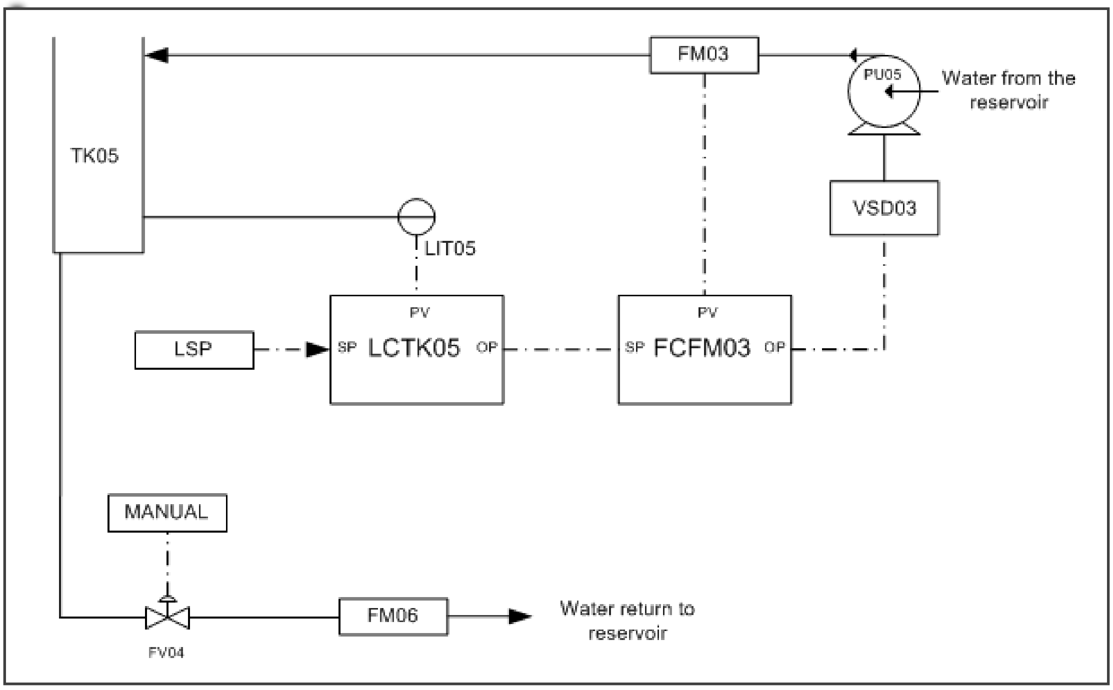

Figure 49 Tank 05 Cascade Control Test Schematic

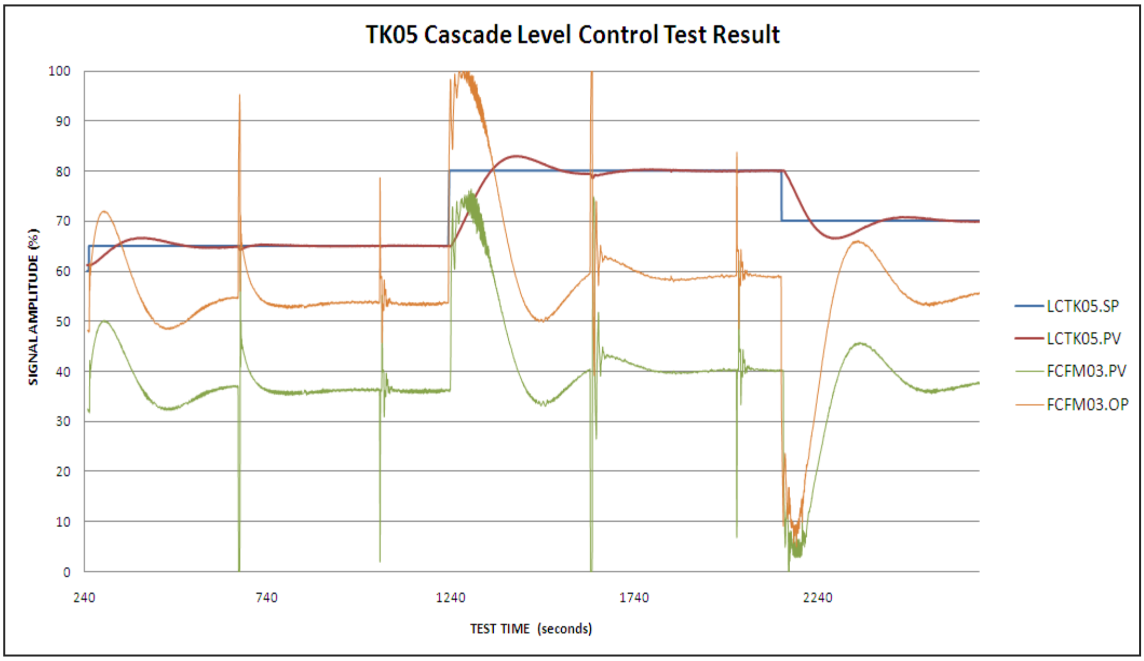

Figure 50 Tank 05 Cascade Control Test Results

7 Conclusions

Undertaking and completing this thesis has greatly increased my knowledge and appreciation of the planning and work required to complete a complex project. The project was large in content and required the thesis to be completed over 12 months. The completion of the thesis has resulted in the Ultimate Water System installation and commissioning being completed and the system ready for operation.

The requirement to install a CompactRIO control system in place of the existing controller was announced early in the project and a specification and order was placed. However the I/O modules of the replacement controller were not identical to the original controller. The replacement of the control system was to have little effect on the overall operation of the Ultimate Water System. However, to achieve this, major control changes were required at Input / Output module level. A great deal of knowledge was gained during the manipulation of the I/O and wiring to make good the installation of the replacement controller.

Areas in which I have increased my knowledge include:

- Increased understanding of LabVIEW, the CompactRIO controller, its I/O modules and their various methods of operation and the work required to adapt them to the requirements of the Ultimate Water System.
- HART based instrumentation and the use of the FLUKE HART communicator to interrogate instrumentation.
- Instrument calibration via the local human Interface panels.
- Ergonomic considerations for the location and orientation of terminals in panels.
- The time taken to complete relatively simple tasks in a large project.

The wiring re-design, installation and termination of the cables and instruments took the bulk of the thesis time and effort. The time allowed for this component in the overall plan was greatly under estimated and resulted in a reduction of the content of the thesis. The development of a LabVIEW control interface for future students will be completed by others.

8 Recommendations For Future Work

The following items were noted during commissioning and testing of the Ultimate Water System. These items should be considered for future modification to enhance the operation of the system.

8.1 Water Cleanliness Issues

The entire Ultimate Water System requires a complete clean out of construction debris. The bottoms of all the tanks are littered with plastic filings which are becoming clogged in the control valves and some of the flow meters. The filter pump requires modification to cause enough turbulence in the reservoir to lift the debris so it can be sucked into the filter pump and filtered out. Filters fitted to the inlets of the pumps would serve the purpose of protecting equipment on the interim.

8.2 Install Filters Before Flow Meters

I recommend the installation of in–line flow filters or sieves before the McNaught geared Flow Meters. These meters are very susceptible to contamination from fluid borne debris, resulting in meter failure. Refer to McNaught Flow Meter Section 5.6.

8.3 Replace Control Valves

During the commissioning and subsequent trialling of the Ultimate Water System very low liquid flows from some of the pumps were noted. Maximum flow rates available from pumps PU02, PU04 and PU06 were approximately 15 litres per minute. Pumpmaster pump data suggests that much higher flows should be possible (refer to Figure 51: PUMPMASTER pump data).

Model	H.P.	K.W.	Flow	20PSI 140KPA	30PSI 210KPA	40PSI 275KPA	50PSI 345KPA	60PSI 410KPA	70PSI 480KPA
JSPA	.5	.37	GPH	554	396	211	39	-	-
			LPM	42	30	16	3	-	-
INOX100	1.0	.75	GPH	686	594	515	330	185	80
			LPM	52	45	39	25	14	6

Figure 51: PUMPMASTER pump data

Pump maximum flow tests

F/Meter	Type	Ctrl	Pump	Flow Path	Flow l/m	F/Meter Range
FIT01	Promag-H	VSD1	PU01	PU01 – TK01	28	0-50 l/min
FIT01	Promag-1H	VSD1	PU01	PU01 – TK03	29	0-50 l/min
FIT01	Promag-H	FV01	PU02	PU02 – TK01	14	0-50 l/min
FIT01	Promag-H	FV01	PU02	PU02 – TK03	15	0-50 l/min
FIT02	Promag-H	VSD2	PU03	PU03 – TK02	29	0-50 l/min
FIT02	Promag-H	VSD2	PU03	PU03 – TK04	30	0-50 l/min
FIT02	Promag-H	FV02	PU04	PU04 – TK02	15	0-50 l/min
FIT02	Promag-H	FV02	PU04	PU04 – TK04	16	0-50 l/min
FT03	McNaught	VSD3	PU05	PU05 – TK05	73	No Range
FT03	McNaught	FV03	PU06	PU06 – TK05	12	No Range
FIT04	McNaught	VSD4	PU09	PU09 – TK01	30	No Range
FT05	McNaught	VSD5	PU08	PU08 – TK02	30	No Range
FIT06	Prowhirl-72	--------	No Pump	TK05 – TK06	80	0-100 l/min
FIT07	Promag-W	--------	No Pump	TK01 – TK06	207	0-300 l/min

To determine if the pumps were capable of delivering more flow it was decided to install a piping blank in place of the control valve and then run the pumps. The blank represented a control valve with very high Cv. Also installed in the blank was a pressure gauge to determine back pressure and hence frictional loss in the pipe work with theoretical maximum flow. The tests were completed by running pump PU06 into Tank 03. The resultant flow was 56 litres per minute with backpressure of 80kPa. Therefore frictional loss in the pipe work was 80kPa at a flow of 56 litres per minute. Referring to the pump data for a 0.37 kW Model JSPA pump in Figure 51, with a back pressure of 140kPa the flow delivered from the pump will be approximately 42 litres per minute, therefore with a pressure of 80kPa (well below 140kPa), the flow delivery available from the pump should be well in excess of 42 litres per minute.

The Cv of the required control valveis given by.

$$Cv = Q\sqrt{SG/\Delta P}$$

where
Cv = control valve flow coefficient
Q = Volumetric Flow Rate (USGPM)
SG = Specific Gravity
ΔP = Pressure Differential (PSI)

Tank 03 is approximately 4 meters above pump PU03 therefore static head due water elevation requirement is approximately 4 meters. Calculating pipe work frictional loss at 80 l/min:

$$Static\ head\ loss = (1000 * 9.81 * 4) = 39.24\ kPa$$

$$Total\ Loss\ @\ 56\frac{l}{min} = 80kPa$$

$$Frictional\ loss\ @\ 56\frac{l}{m} = (80 - 39.24) = 40.76\ kPa$$

The Cv of the installed control valves is 1.5, however the flow through these control valves is low. Re-calculating the Cv for the valve required to deliver 42 l/m, the highest recommended flow on the pump data plate.

From the pump data plate in Figure 51.

Flow = Q = 42 l/min = 11.10 USgpm

Pressure = 140 kPa

Recalculating frictional loss at 42 l/m

Since frictional loss is proportional V^2

$$Total\ pressure\ loss\ @\ 42\frac{l}{m} = \left(\left(\frac{42}{56}\right)^2 * 40.76\right) + 39.24 = 62.16\ kPa$$

$$Required\ CV\ \Delta pressure\ @\ 42\frac{l}{m} = 140 - 62.16 = 77.83kPa = 11.288psi$$

$$Cv = Q\sqrt{SG/\Delta P}$$

$$Cv = 11.1/\surd(\frac{1}{11.288})$$

$$Required\ Cv = 3.3$$

8.4 Eliminate Seizing Control Valves

Control valves FV01 FV02 and FV03 all suffered from seizure when the valves were in the closed position. Investigation revealed that when the valves are in the closed or near to closed position the clearances in the valves are very small. Debris in the form of plastic particles from the installation of the pipe work were being sieved out of the flow and packed into the small close tolerance areas of the valve where they were jammed in tight each time the valve closed off. Murdoch staff installed a larger filter pump, however the flow is still insufficient to cause turbulence in the reservoir to improve filtering to remove all debris. Turbulence in the reservoir is required to cause the particles in the bottom of the reservoir to lift and be sucked into the intake of the filter pump. I suggest installing pipe work to direct return filter flow into each of the reservoir compartments. The CompactRIO control system could be used to switch flow between compartments to move the particles towards the filter and thus improve filtering. It is also recommended to install the water bacterial control unit as its installation will prevent algae and bacterial growth leading to future system blockages.

8.5 Control Discharge of Tanks 01 - 04

After Ultimate Water System commissioning some basic controller a tests were conducted. A simple level control loop was set up controlling the level of Tank 03 via VSD01 and PU01. To simulate a process after the tank the tank drain valve was used to drain water back to the reservoir. However the drain valve is a gate valve with ON-OFF characteristics so setting and maintaining a flow of approximately 16 litres per minute was extremely difficult.

The test was repeated on Tank 05, which has a control valve and flow transmitter fitted in the discharge pipe work of the tank. This test proved much easier to set up and control because the discharge flow from tank 05 could be monitored and controlled from the LabVIEW control scheme.

It is recommended that control valves and flow meters are installed into the discharge pipe work from Tanks 01 - 04. The only monitored and controlled return flow to the reservoir is from tank 05 via FIT06 and FV04. Tank 01 has a flow meter installed in the discharge pipe, however there is no flow control valve fitted in the return pipe to the reservoir, only an open/close solenoid valve. If a control valve was installed in place of the solenoid valve and possibly a flow meter and control valve installed in the discharge from tank 02 to the reservoir, then more avenues for complex control systems become available.

8.6 Complete Cable Tagging in the UWS Control Panel

As discussed in section 6.2, the cable numbering system employed in the original design of the Ultimate Water System was based on the terminal number to which the cable terminated, therefore a cable could have different numbers at each end. The new system has unique numbers for each cable. A large number of cables were changed to the new numbering system, however not all of the incorrect cable tags were rectified. It is recommended that the remaining cables with the old numbering system be re-tagged with unique numbers.

8.7 Install UWS Lights

The original design of the Ultimate Water System included lights mounted under the upper tanks. The lights were intended for future display. The lights were not fitted because the light fittings were not available and the control relays were required to control the SEW variable speed drives. It is recommended to source the required relays and install the lights as per the original design.

8.8 Install Motor Isolator Status Indication

The original Ultimate Water System design included motor isolator status indication to be available to the operator (refer section 5.5). It is recommended to install the isolator status indication in the future. The design could be modified by installing isolating switches with normally open auxiliary contacts. The additional cores in the power cables could then be used to convey contact status back to the control system, eliminating the problems involved with sensing motor power at the switches.

8.9 Install Diaphragm Pump Air Supply

Two separate pneumatic air supplies were installed into the Ultimate Water Supply, one for the control valve positioner instrumentation and one for the solenoid valves. These supplies are adjustable on separate filter regulators. It was noted during commissioning that the diaphragm pump required a higher pressure than that required by the solenoid valves to operate (Refer to Section 5.1, Commissioning Problem Resolution). The diaphragm pump requires a separate pressure regulated air supply. The pressure regulator should be mounted adjacent to the installed pressure regulators on the control cabinet. The pressure regulator should be capable of supplying 200kPa to the diaphragm pump PU07.

8.10 Implement HART Protocol Instrumentation.

Utilise HART instrumentation. The level and flow transmitters installed in the Ultimate Water System all have HART capability. The control system could be modified to use this capability in several ways such as:

- The installation of splitters in several of the transmitter control signal loops would make the HART signal available. HART could then be used to change the range and zero calibration of the transmitters, send back environmental information or use the digital signal as a measured process variable.

- A HART valve positioner could be installed allowing students to appreciate valve condition monitoring and on line diagnostic capabilities.
- A possible future project could be to collect the HART data using LabVIEW.

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