AP-100 Advanced Process Controller

User Manual

Version: 2.20

Preface

Thank you for purchasing Hazelton Technologies - AP-100 Advanced Process Controller. This manual contains instructions for mounting, functions, operations and notes when operating the AP-100. For model confirmation and unit specifications, please read this manual carefully before starting operation. To prevent accidents arising from the misuse of this controller, please ensure the operator receives this manual.

Notes

- This instrument should be used in accordance with the specifications described in the manual. If it is not used according to the specifications, it may malfunction or cause fire.
- Be sure to follow the warnings, cautions and notices. Not doing so could cause serious injury or accidents.
- The contents of this instruction manual are subject to change without notice.
- Care has been taken to assure that the contents of this instruction manual are correct, but if there are any doubts, mistakes or questions, please inform our sales department.
- This instrument is designed to be installed in a control panel. If it is not, measures must be taken to ensure that the operator cannot touch power terminals.
- Any unauthorized transfer or copying of this document, in part or in whole, is prohibited.
- Hazelton Technologies Pty Ltd. is not responsible for any damages or secondary damages incurred as a result of using this product, including any indirect damages.

Safety Precautions (Be sure to read these precautions before using this instrument.)

The safety precautions are classified into categories: “Warning” and “Caution”. Depending on circumstances, procedures indicated by ⚠ Caution may be linked to serious results, so be sure to follow the directions for usage.

⚠ **Warning**
Procedures which may lead to dangerous conditions and cause death or serious injury, if not carried out properly.

⚠ **Caution**
Procedures which may lead to dangerous conditions and cause superficial to medium injury or physical damage or may degrade or damage the product, if not carried out properly.

⚠ **Warning**

- To prevent an electric shock or fire, only Matsushita or qualified service personnel may handle the inner assembly.
- To prevent an electric shock, fire or damage to instrument, parts replacement may only be undertaken by Hazelton Technologies Pty Ltd or qualified service personnel.

⚠ **Electrical Safety**

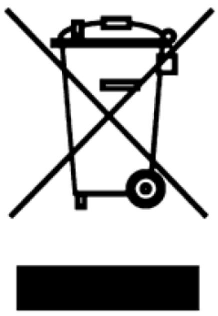
- This equipment complies with the requirements of CEI/IEC 61010-1:2001-2 'Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory Use' and complies with US NEC 500, NIST and OSHA.
- If the equipment is used in a manner NOT specified by the Company, the protection provided by the equipment may be impaired.

Safety Precautions

- To ensure safe and correct use, thoroughly read and understand this manual before using this instrument.
- This instrument is intended to be used for industrial machinery, machine tools and measuring equipment. Verify correct usage after consulting purpose of use with our agency or main office. (Never use this instrument for medical purposes with which human lives are involved.)
- External protection devices such as protection equipment against excessive temperature rise, etc, must be installed, as malfunction of this product could result in serious damage to the system or injury to personnel. Also proper periodic maintenance is required.
- This instrument must be used under the conditions and environment described in this manual.
- Hazelton Technologies Pty Ltd does not accept liability for any injury, loss of life or damage occurring due to the instrument being used under conditions not otherwise stated in this manual.

EC Directive 89/336/EEC

- In order to meet the requirements of the EC Directive 89/336/EEC for EMC regulations, this product must not be used in a non-industrial environment.



In order to comply with EU Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE):

This product may contain material which could be hazardous to human health and the environment. DO NOT DISPOSE of this product as unsorted municipal waste. This product needs to be RECYCLED in accordance with local regulations, contact your local authorities for more information. This product may be returnable to your distributor for recycling - contact the distributor for details.

Contents

1. INTRODUCTION

The AP-100 Advanced Process Controller is the combination of the follow devices all in the one easy to use and customise unit.

- **2 x PID Controllers** - The AP-100 has 2 single PID controller that can be configured as Master and Slave Cascade PID control configuration. Controllers can be configured for Open-Loop, Feedback and Feed-Forward modes. Both PID controllers have very fast execution times and can be user selected to execute up to 50 times per second (50 Hz). The Input signal range from 0.00% to 100.00% can be divided up into 1 to 5 zones. Each Zone can be configured to have separate Proportional, Integral and Derivative gain constants. The enables better performance for each PID Controller.

- **Analogue & Digital Operations** – The AP-100 is able to perform advanced mathematical operations on Input & Output signals that are either Digital or Analogue, in the form of Equations. Up to 5 floating-point (32-bit) intermediate variables are available. Maths operations such as Sin, Cos, Tan, Log10-, Exp and Sqrt are available for implementing any equation or algorithm. Some examples of Equation uses are:
    - To assign signals to PID Controllers.
    - Create feed-forward & feed-back signals.
    - To linearize Input & Output signals.
    - Add/subtract signals from each other.

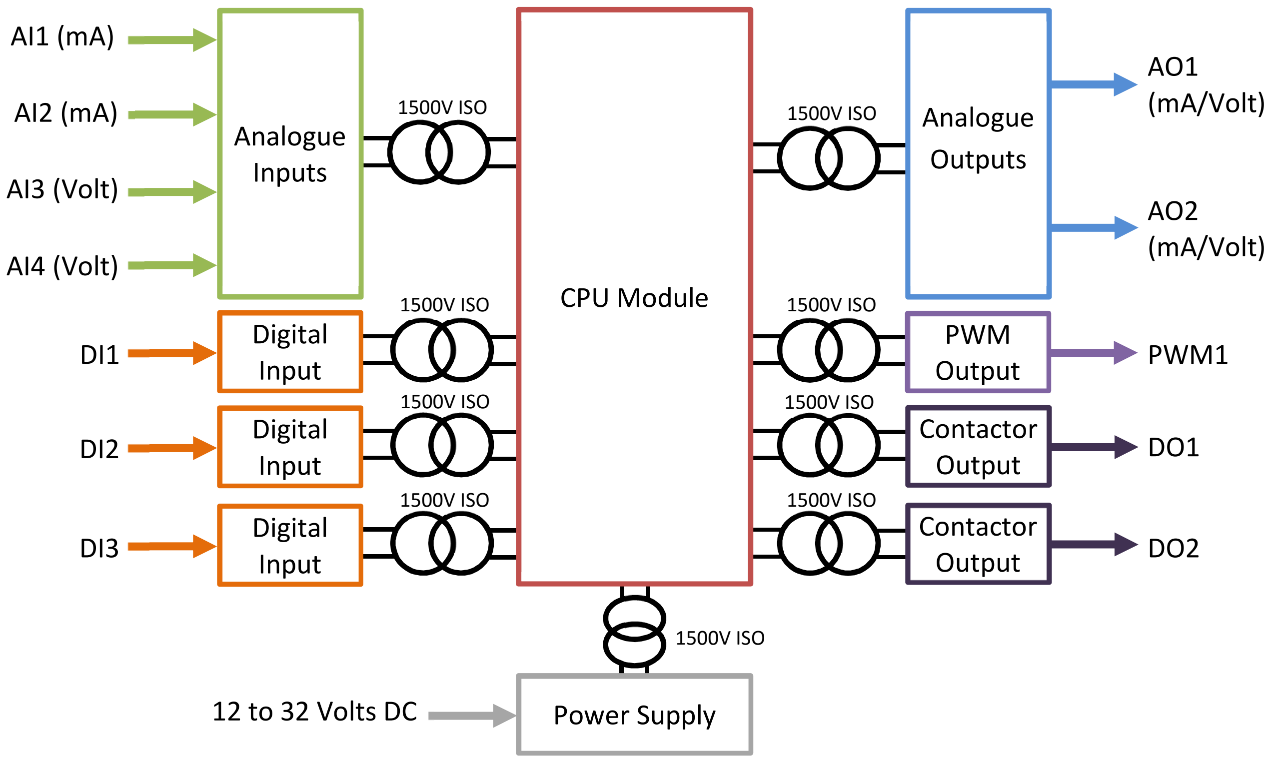
- **Micro-PLC** – Compute logical expressions with configurable IF Statements. The AP-100 is able to evaluate logical expressions to execute certain equations based on whether the logical expressions are true or false. IF Statements can also be used to log an event in the Alarm & Events log. The AP-100 device supports two different 'IF Statements' which, when enabled, will execute 100 times per second (every 10mS) during each CPU cycle.

- **Trend Recorder & Viewer** – View & Record trends of analogue Input & Output signals, as well as intermediate variables. Use the touchscreen to zoom In & Out as well as forward & back in time of any trends. Recorded trend data with sample rates as fast as 3 samples per second, to 8Gb of internal flash memory. Insert a USB memory device into the AP-100 to save trend data in .CSV to later be opened and viewed in MS Excel (or spreadsheet program).

- **Alarm & Event Recorder & Viewer** - The AP-100 can capture 10,000+ Alarm & Events and save them to internal flash memory with the recorded Date, Time, Type and Description. The easy to used touchscreen interface allows the user to view Alarm & Events with Up & Down scroll buttons. Input channels can be configured to generate Alarm or Events if the input signal comes within specified ranges. IF Statements can also be configured to generate an Alarm or Events if an expression comes True. Insert a USB memory device into the front of the AP-100 to save the data as a .CSV file that can later be viewed in MS Excel (or spreadsheet program).

The AP-100 device has been designed with the latest 32-bit microprocessor technologies with only high quality electrical components used. This device is designed to be easy and intuitive to program and to use through the 4.3" colour touch-screen without the need for external PC computer or cables.

The AP-100 device has 1500 Volt fault isolation between Inputs, Outputs and Power Supply using the EN61010 test conditions. The isolation diagram is shown below.



1.1. Application Examples

The following describe some application examples of the AP-100 Advance Process Controller being applied. For full details and setup instructions see the Case Studies at the end of this User Manual.

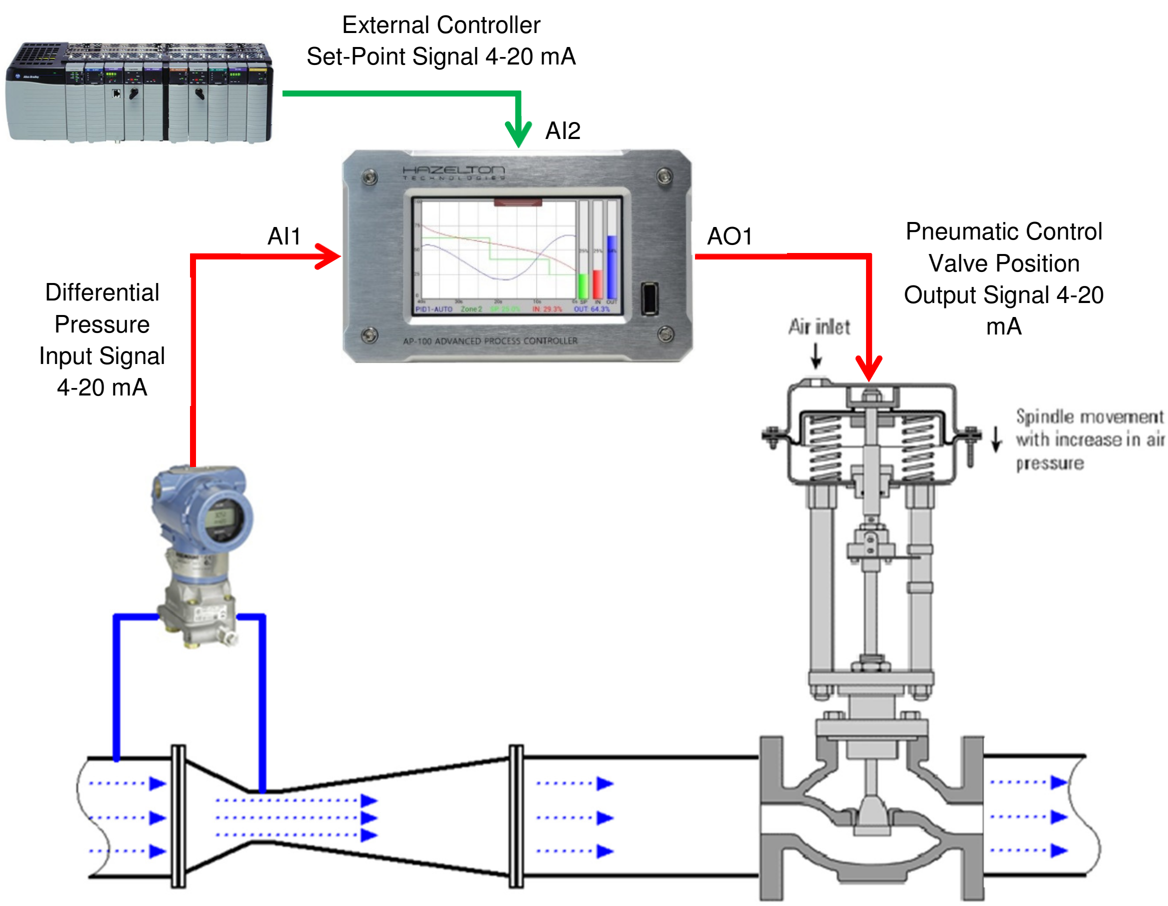
1.1.1. Case Study - Liquid Chlorine Flow Controller

In this example, the AP-100 Advanced Process Controller shall be used as a PID flow controller for a liquid Chlorine line. The flow rate is to be measured with a venturi flow meter and differential pressure transmitter, which shall be a 4-20mA input signal. The AP-100 device shall use an internal equation to convert the differential pressure signal into a flow rate. This flow rate value shall then be the input into the internal PID Controller to the AP-100 device.

The PID Controller's Output shall drive a 4-20mA signal to a pneumatic control valve that has a non-linear equal percent profile between stem travel and flow rate through the valve. The AP-100 device shall use an internal equation to convert the output from the internal PID Controller into equivalent equation percent valve stem travel signal.

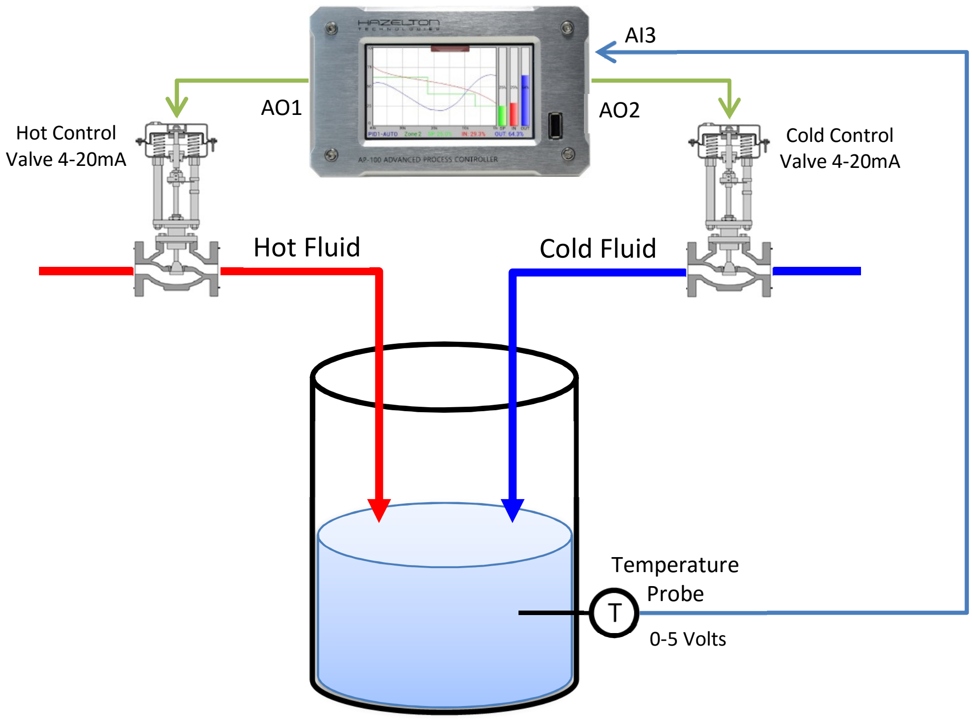
The AP-100 device shall have a second 4-20mA input signal from an external PLC that shall be the Set-Point signal for the PID controller, as shown below.

See Section 13 of this manual for full details and setup instructions.



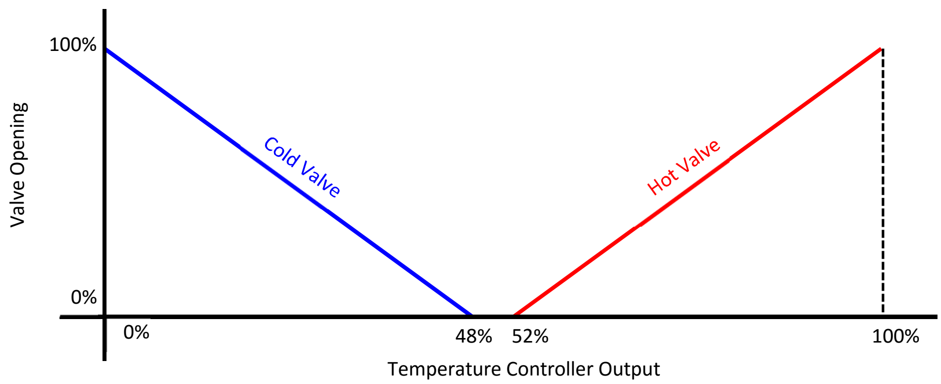
1.1.2. Case Study – Split Range Temperature PID Controller

In this case study the AP-100 Advances Process Controller is being used to control the temperature of fluid within a tank with its internal PID Controller, as shown below. The AP-100 device reads the fluid temperature from an RTD temperature probe that outputs a 0 to 5 Volt signal for 0 to 200˚C respectively. The AP-100 shall control the fluid temperature by manipulating two control valves. One control valve is on a hot fluid inlet line and the other is on a cold fluid inlet line into the tank. Both control valves receive a 4 to 20 mA signal for 0% to 100% open respectively.



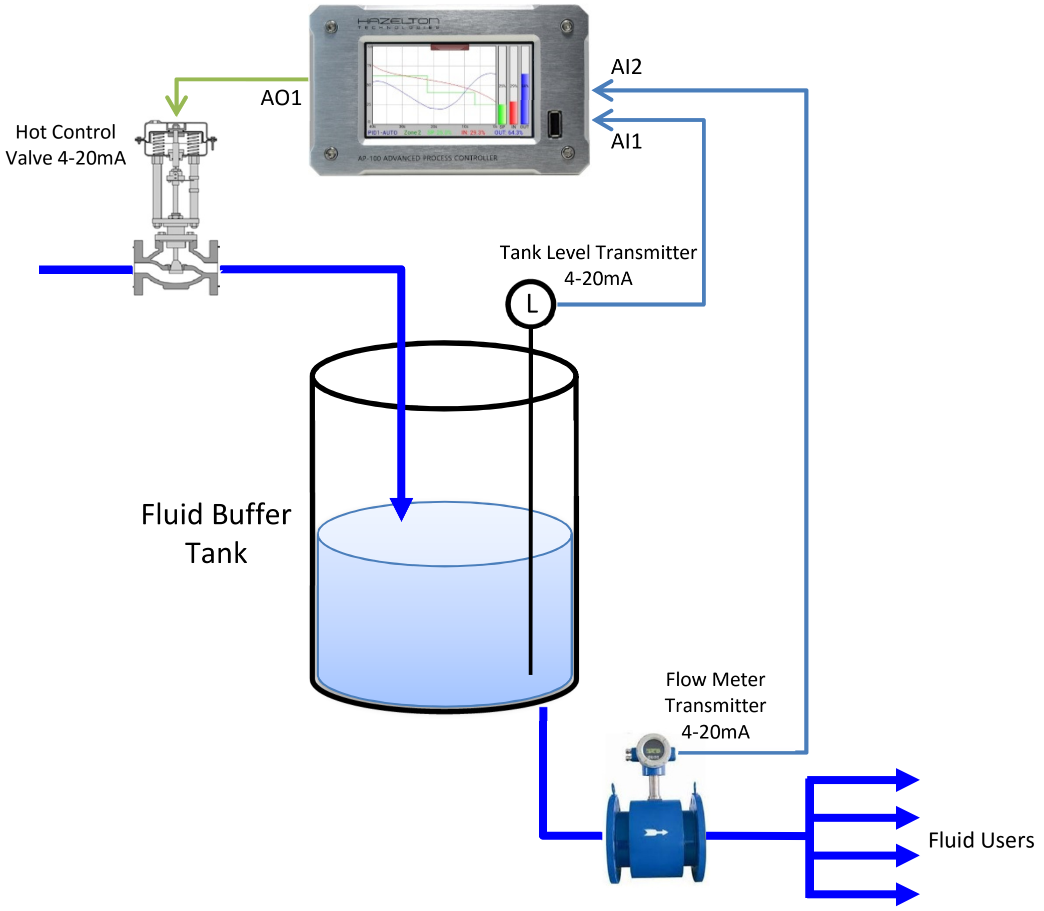
The 0% to 100% range of the Output of the PID Controller is split in two between the two valves. If the controller output is between 0% and 48%, the cold fluid valve is operated. This valve is fully open when the controller output is 0% and fully closed when the controller output is 48%. If the controller output is between 52% and 100%, the hot fluid valve will be operated. At 52% controller output, the hot fluid valve starts to open and it is fully open at 100%. There is a dead-band between 48% and 52% of controller output where both valves remain closed. The dead-band is to prevent valve seat ware-out from the controller constantly switching between the two valves.

See Section 14 of this manual for full details and setup instructions.

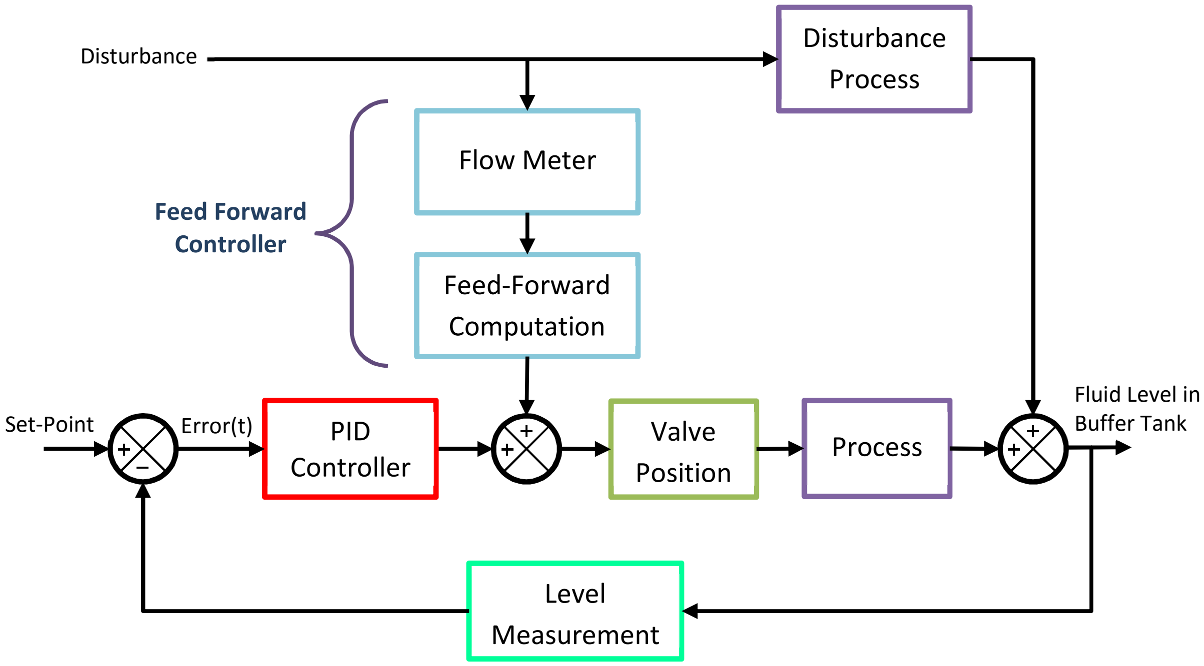


1.1.3. Case Study - Feed-Forward PID Control

This case study shall analyse a Fluid Buffer Tank level PID controller scenario and how to implement a Feed-Forward PID Controller scheme to improve performance. The process under control is illustrated below. The level within a Fluid Buffer Tank is controlled by a control valve on an inlet line to the tank. The level of the Fluid Buffer Tank is measured with a Level Transmitter. There is an outlet line from the Fluid Buffer Tank to supply fluid to the downstream users. This flow meter is used to measure the disturbance caused by downstream users, and shall be used to predict the impact that it will have on the fluid level and then computes pre-emptive control actions. The goal is to maintain the fluid level to the controller Set-Point value (fluid level = Set-Point) throughout the disturbance event.



The control system block diagram for this feed-forward PID controller is shown below. The "Disturbance" input is one or more of the downstream users having a sudden and significant change in fluid usage.

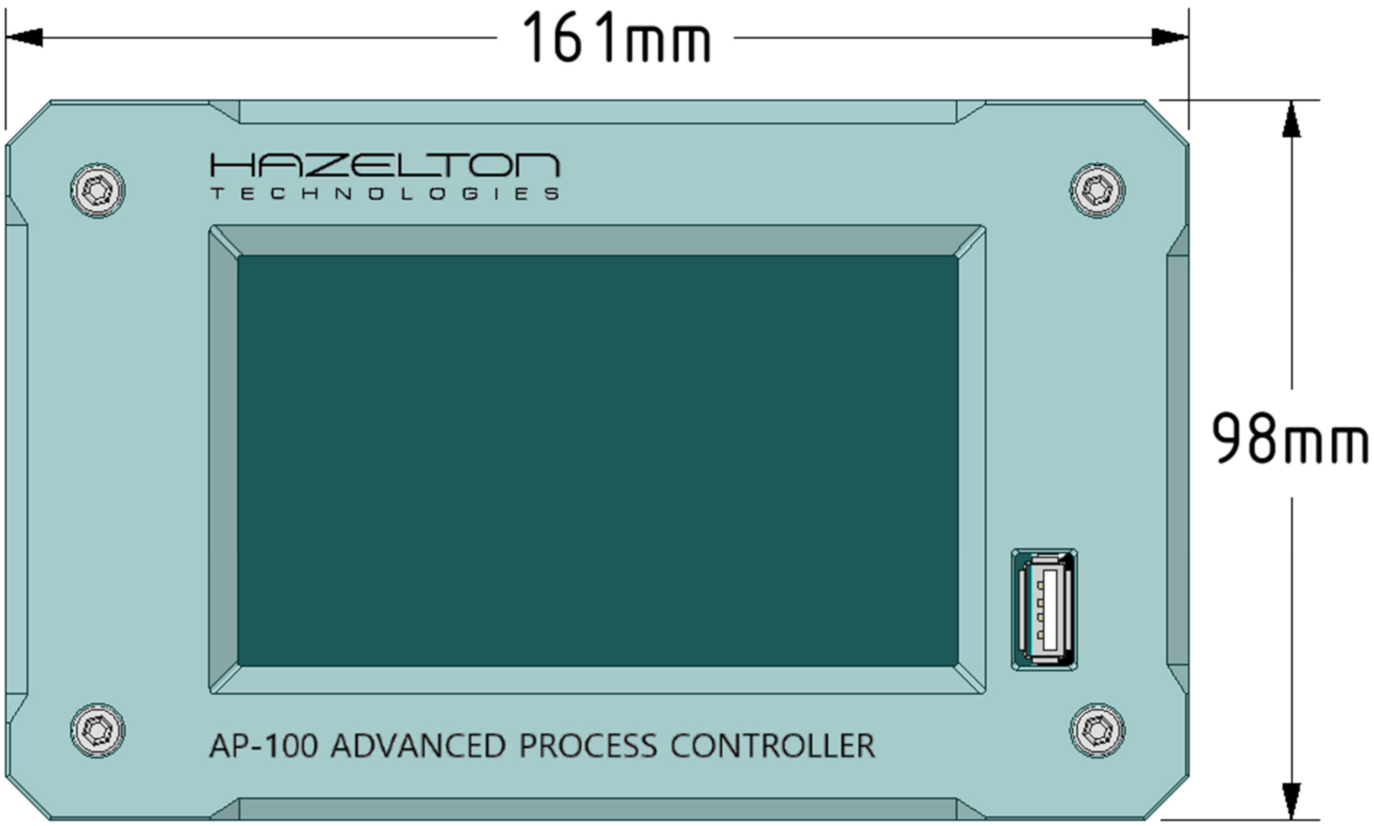


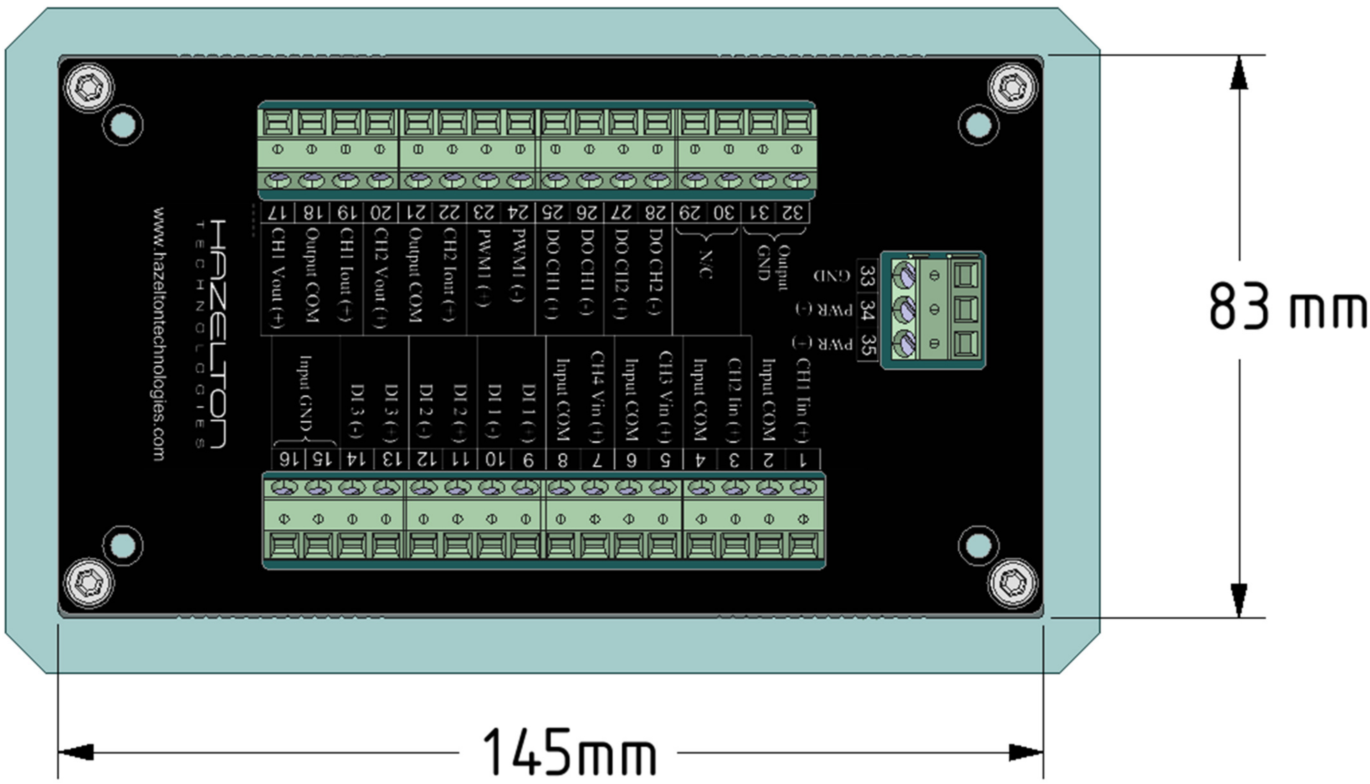
2. INSTALLATION

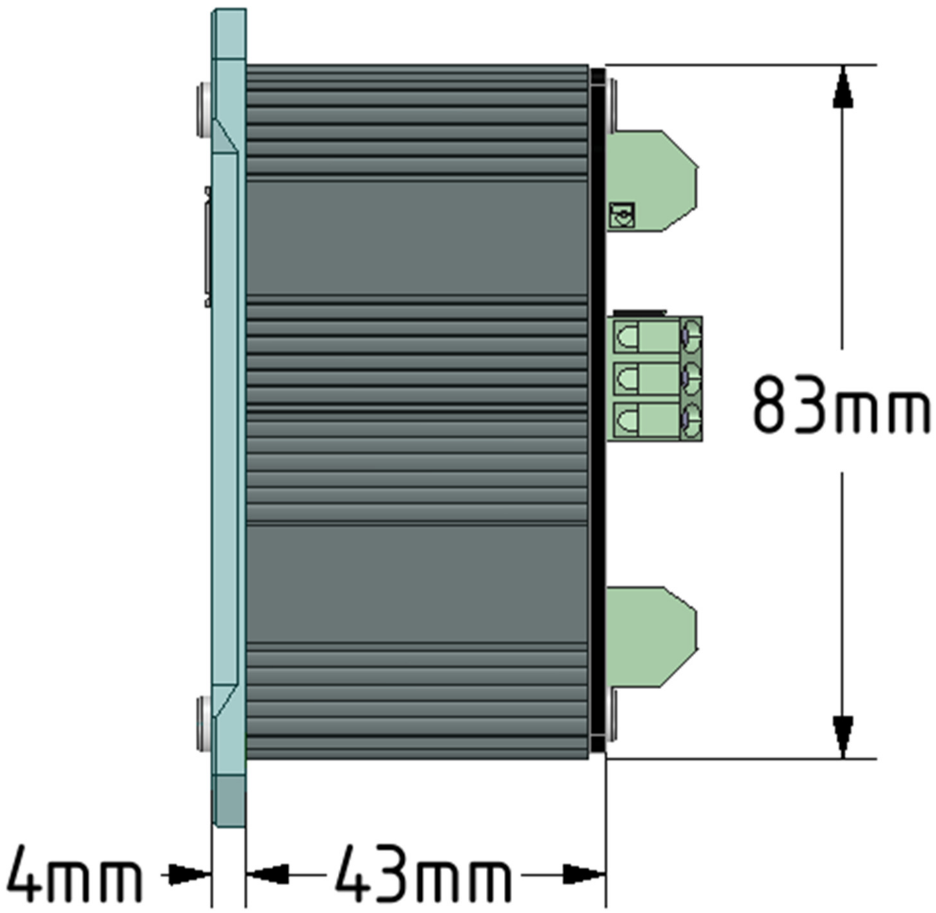
2.1. Unpacking the Device

The instrument is despatched in a special pack, designed to give adequate protection during transit. Should the outer box show signs of damage, it should be opened immediately, and the contents examined. If there is evidence of damage, the instrument should not be operated and the local representative contacted for instructions. After the instrument has been removed from its packing, the packing should be examined to ensure that all accessories and documentation have been removed. The packing should then be stored against future transport requirements.

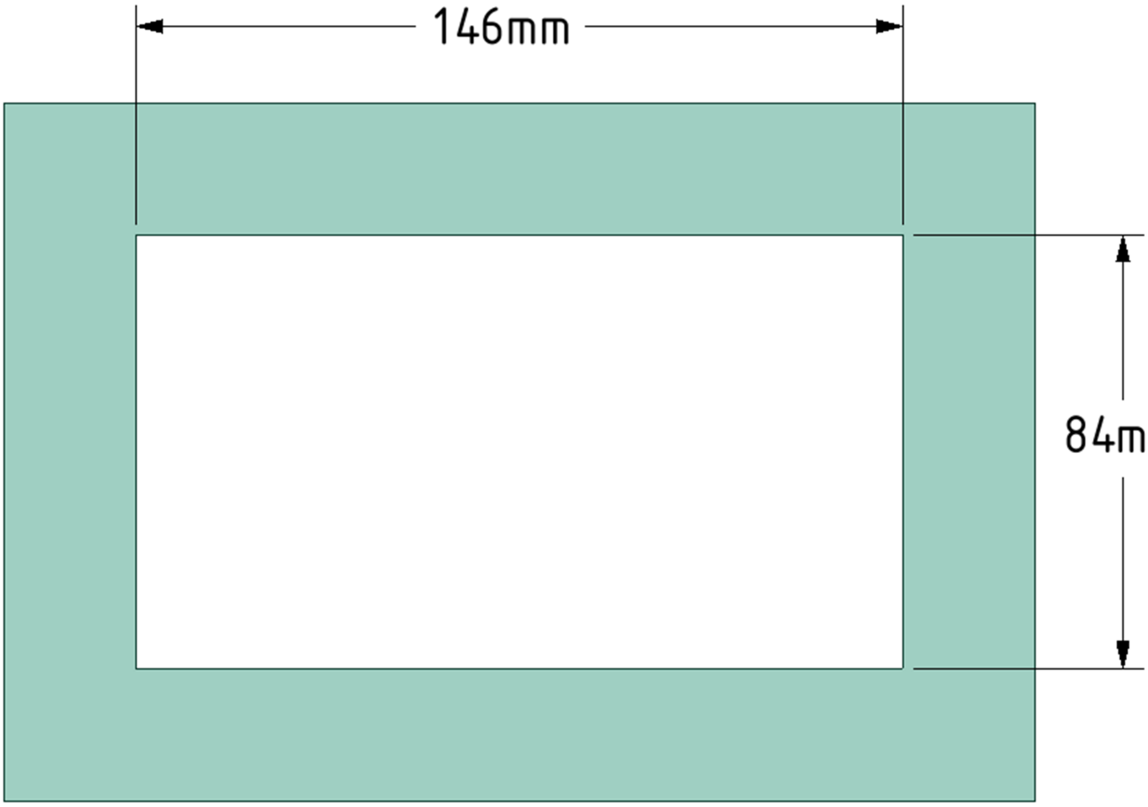
2.2. AP-100 Device Dimensions




www.hazeltontechnologies.com
83 mm
145mm

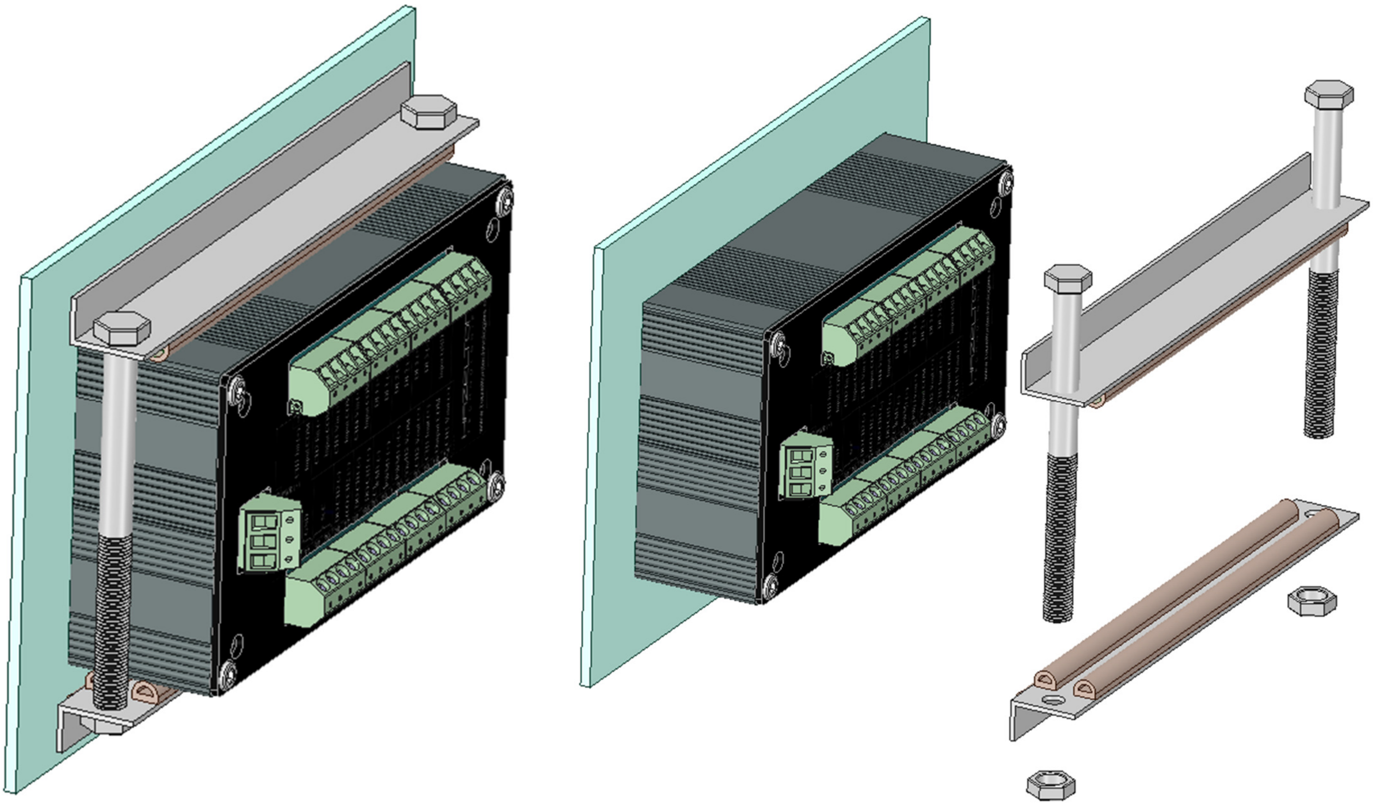

83mm
4mm
43mm

2.3. Panel Cut-Out Dimensions



2.4. AP-100 Device Mounting Support Brackets

Insert the AP-100 device into the panel cut-out and secure with the mounting brackets as supplied.



3. MAIN MENU

Below is the Main Menu screen of the AP-100, it is the

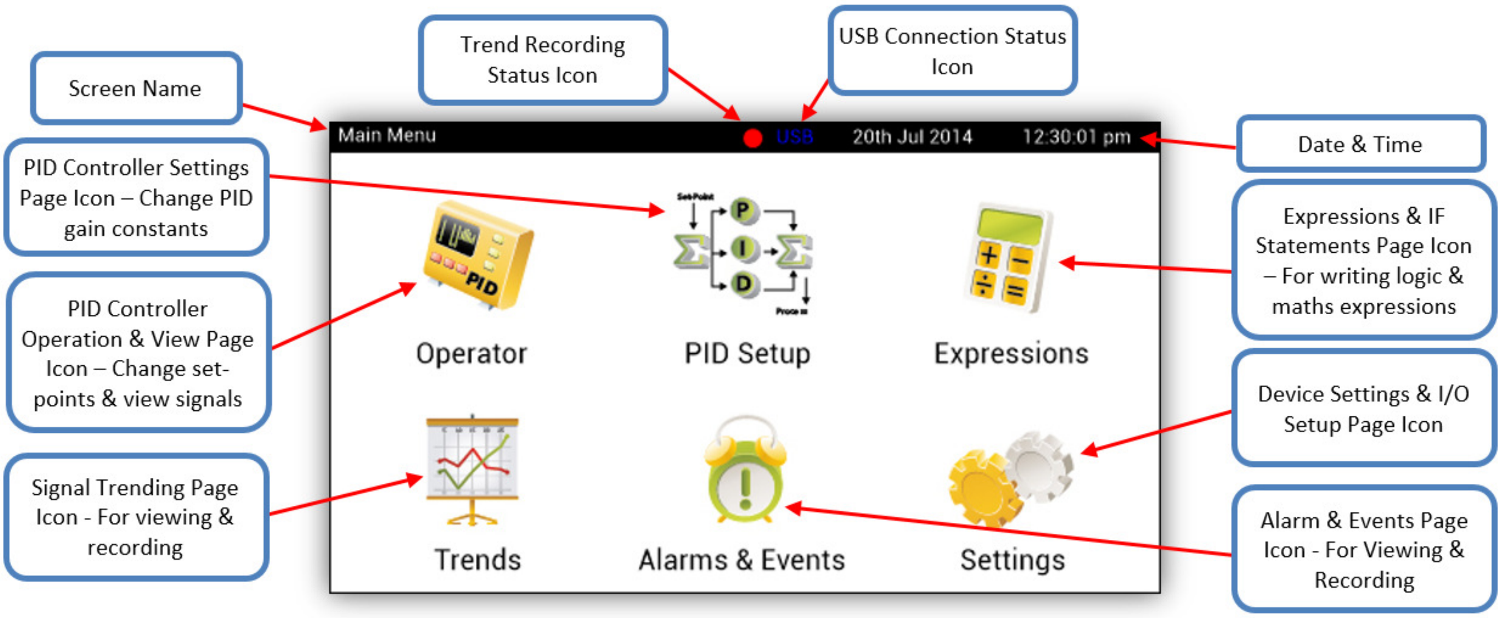
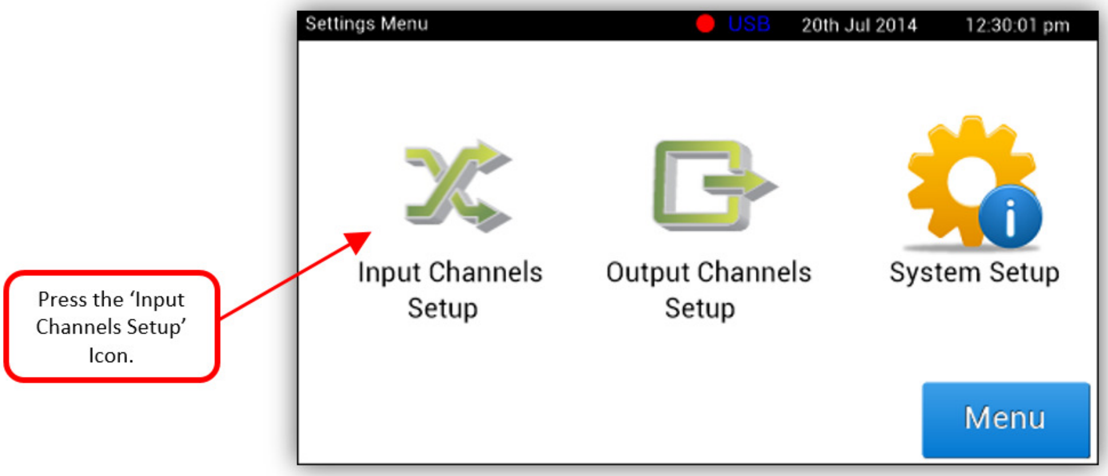


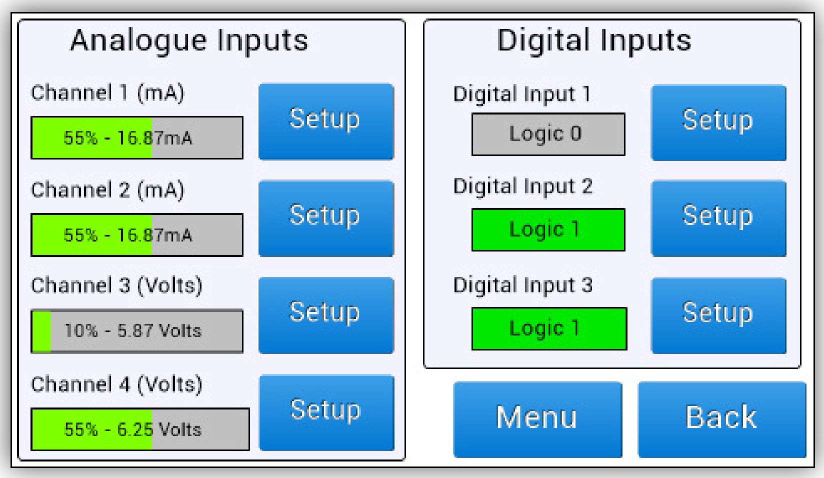
Figure 1. AP-100 Main Menu Screen

4. ANALOGUE & DIGITAL INPUT CHANNELS SETUP

To navigate to the Analogue & Digital Input Channels summary, firstly press the 'Settings' icon on the Main Menu to display the 'Settings Menu' screen as shown below. From here the user can navigate to setup analogue and digital signal Inputs and Outputs. Also internal settings can be changed such as the time and date. Press the 'Input Channels Setup' icon to display all input channels and settings.



Below shows the 'Input Channels Setup' menu screen. This screen is used to navigate to the setup of each Input channels. The user can also use this screen to easily view the current values of the analogue and digital input channels. As shown below, channels 1 and 2 read mA signals (0-22mA, 0-20mA & 4-20mA) whereas channels 3 and 4 read Voltage signals (0-10Volts, 0-5Volts, +/-5Volts & +/-10Volts). To setup Channel 1 (mA) press its corresponding 'Setup' button.



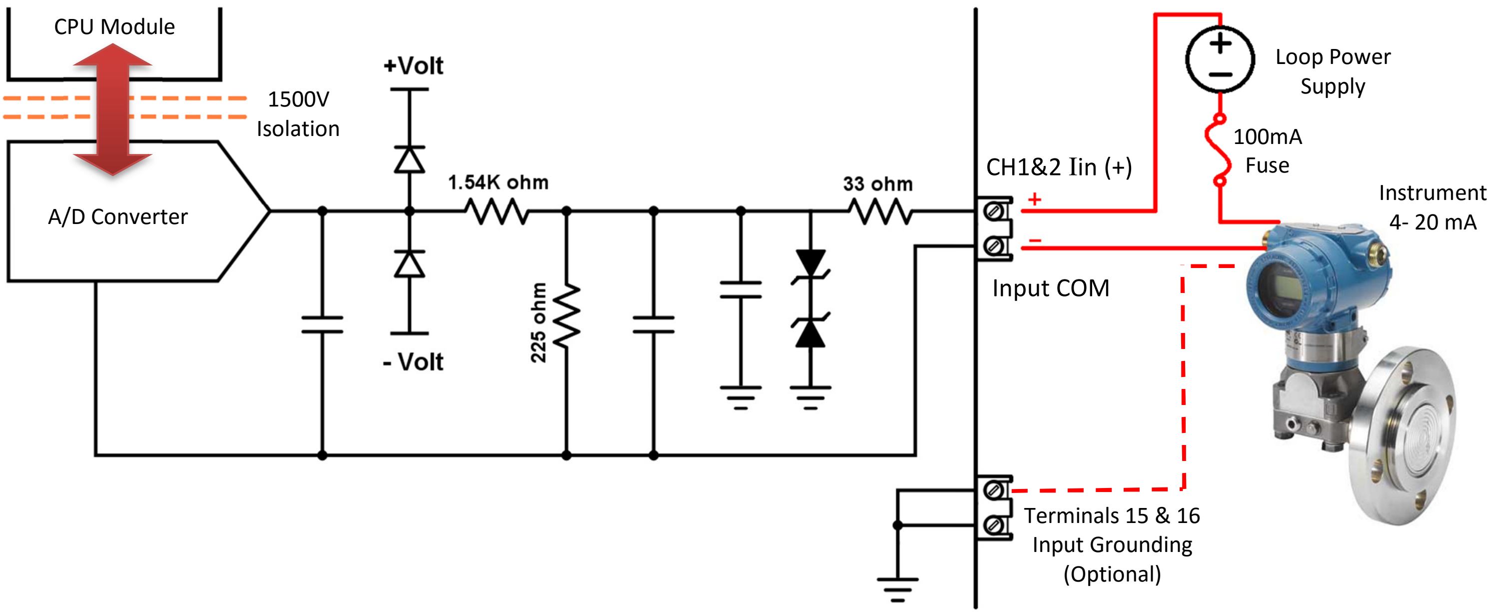
See 'Equations Setup' Section 6 for details as to how to use input read values.

4.1. Analogue Input (mA) Channels 1 & 2 Setup

The AP-100 Advanced Process Controller has two channels (CH1 & 2) that read mA signals and is designed for the most demanding industrial control applications. These inputs have been designed with the following features:

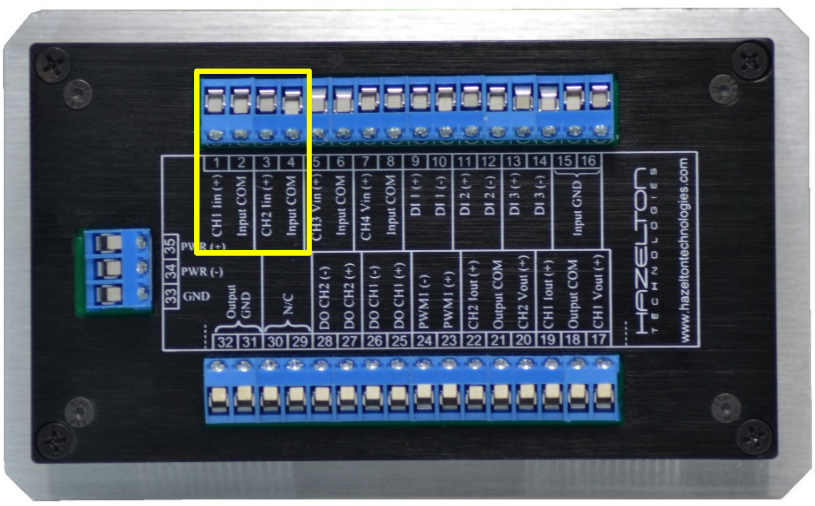
- CPU scans these inputs 100 times per second (every 10mS).
- Read mA signals with a selectable upper and lower ranges of any value between 0 to 22mA.
- Each input channel has a resolution of 0.02 % over full range.
- Each input channel has a 1500-volt isolation from the CPU module, outputs channels and power supply.
- Each channel has over voltage and over current protection.
- Excellent signal to noise ratio including 50/60 Hz waveform cancelation.
- All input channels are designed to be external powered to give greater design flexibility.
- All channel settings data is stored in non-volatile memory and will remain after power off.
- 100mA in line fuse is recommended.

The below diagram shows the internal circuitry of the Analogue Input (Volts) Channels and recommended connection wiring diagram.



4.1.1. Electrical Terminals

The Analogue Input (mA) Channels 1 & 2 terminals are highlighted below.



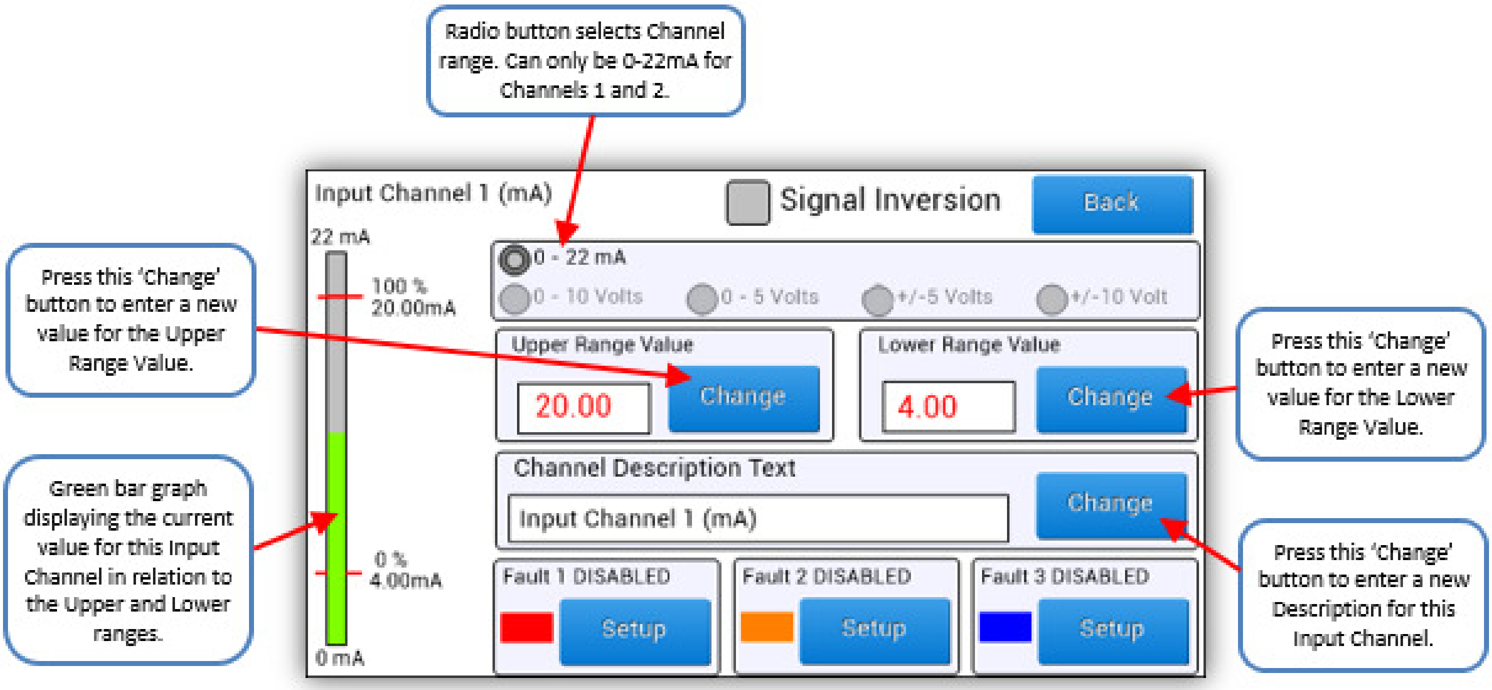
4.1.2. Range Setup

Below shows the setup screen for the Analogue Input Channel #1. This screen is identical to Analogue Input Channel #2 and therefore this following information applies to both Channels #1 and #2.

The full range of the Channels #1 and #2 is from 0mA to 22mA. Hence, the voltage range radio buttons are disabled and greyed out in the top box on the screen, and only the '0-22mA' radio button is selectable.

Analogue Input Channel's 1 & 2 register within the AP-100 device as decimal number between 0.000% to 100.000%.

To set which upper range mA value will translate to 100.000%, press the corresponding 'Change' button in the 'Upper Range Value' field and enter the desired value. To set which lower range mA value will translate to 0.000%, press the corresponding 'Change' button in the 'Lower Range Value' field and enter the desired value.



> **Warning**
>
> - Before making setting changes to an online system first consider how this change effects associated output.
> - It may be necessary to shutdown plant or equipment before making this change.

4.1.3. Description

To change the Input Channel's Description, press the corresponding 'Change' button and entered the desired description text for this channel, as shown in the above figure.

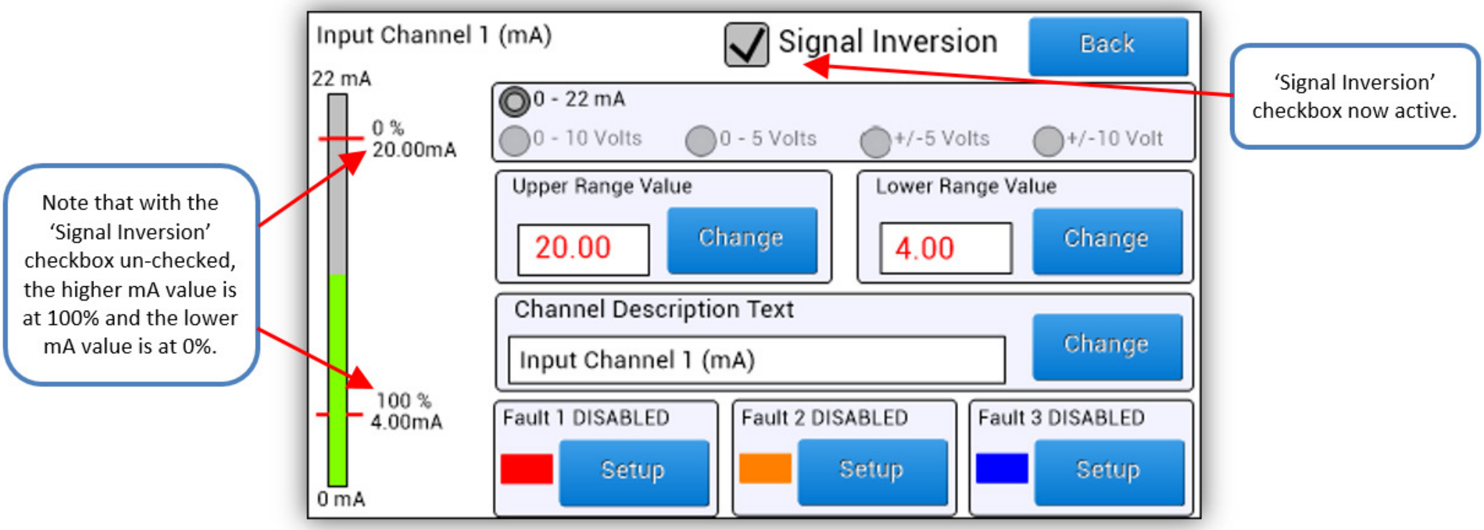
4.1.4. Signal Inversion

Notice in the above screen the large 'Signal Inversion' checkbox is un-checked and therefore the higher mA range value of 20.00mA corresponds to the 100% value and the lower mA range value of 4.00mA corresponds to the 0% value.

The below screen now has this 'Signal Inversion' checkbox active. Now the input signal has been inverted and the higher mA range value of 20.00mA corresponds to the 0% value and the lower mA range value of 4.00mA corresponds to the 100% value.

Warning

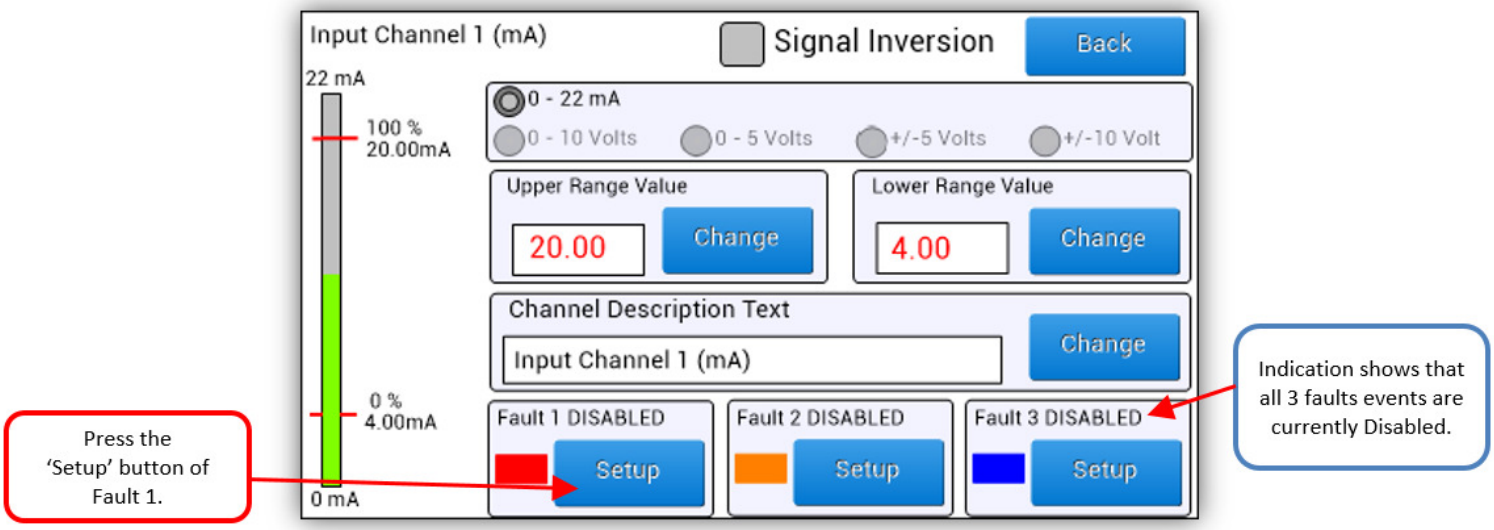
- Before making setting changes to an online system first consider how this change effects associated output.
- It may be necessary to shutdown plant or equipment before making this change.



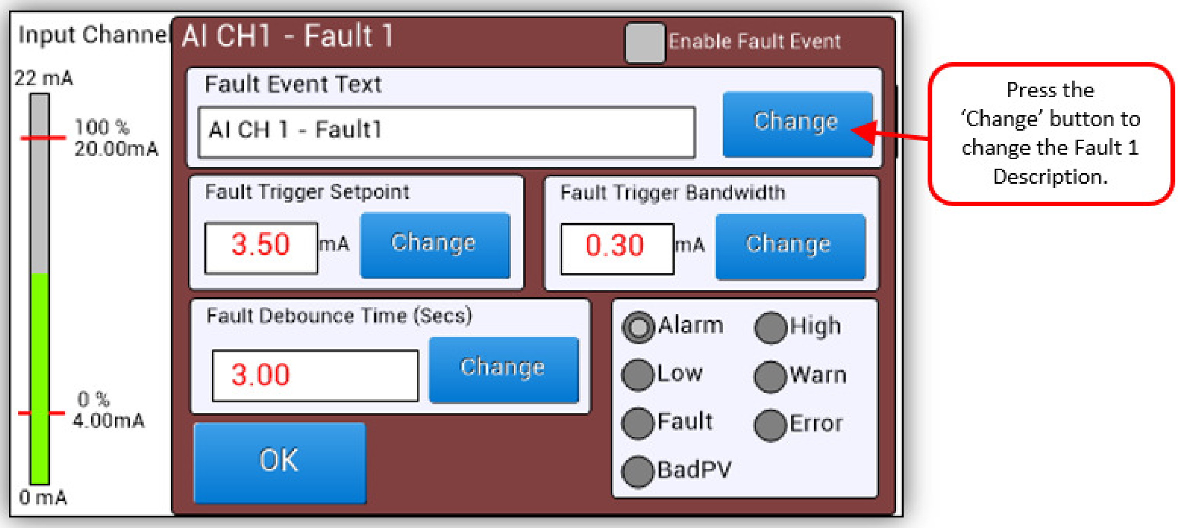
4.1.5. Fault Event Setup

Fault events can be setup to generate an Event if the Input signal comes within the range of the setup Fault band (see Alarm & Event section for more information on events). This can be useful for generating a recordable event to capture if a connected instrument drifts out of range, if there is an open-circuit, or if the instrument goes into fault (commonly 3.5mA signal is used).

As shown below, the are 3 coloured bands (Red, Green, Blue) that correspond to 3 configurable Fault events. To setup the 'Fault 1' event to record a fault event if the input signal goes over-range (ie. any value above 20mA), press the corresponding 'Setup' button for Fault 1 as shown below.

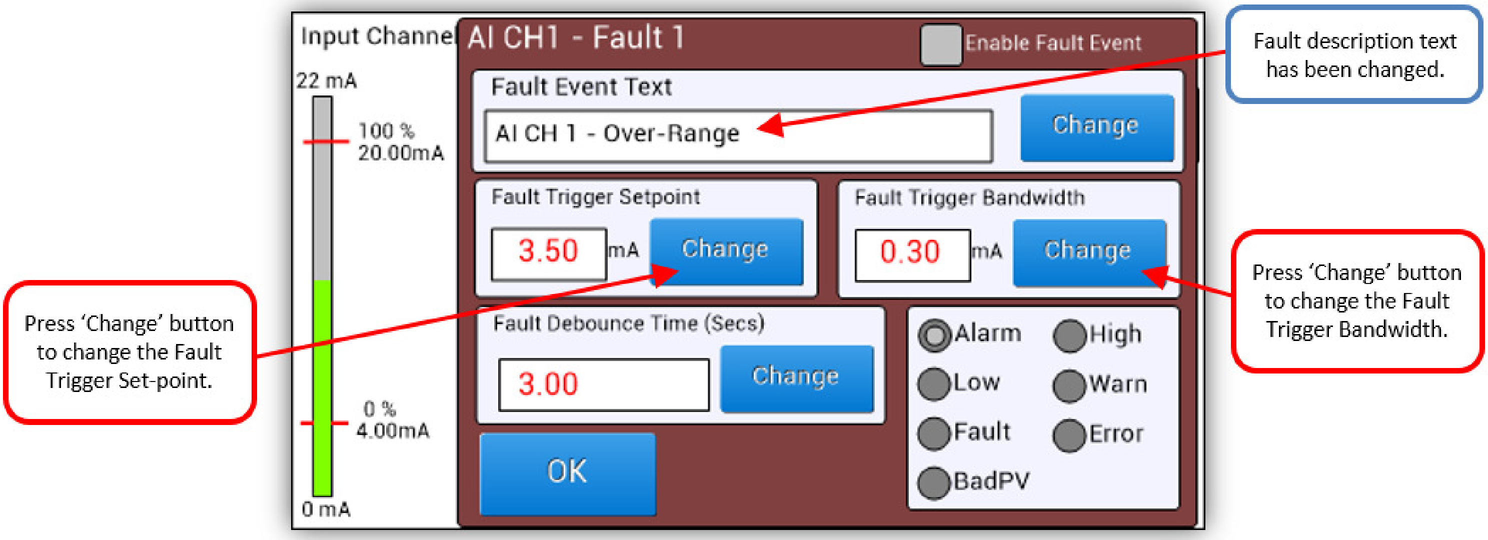


The Fault 1 setup dialogue box shall appear as shown below. Currently 'Enable Fault Event' checkbox is not selected and therefore this fault is disabled. First we shall change the 'Fault Event Text' by pressing the corresponding 'Change' button.

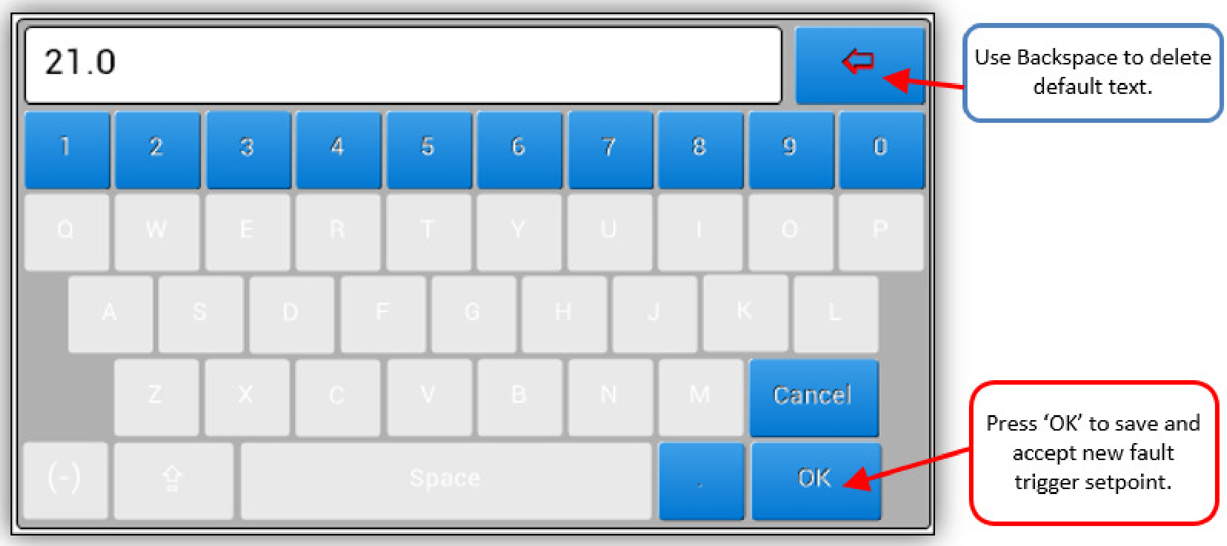


The keyboard screen shall appear. Use the Backspace key to delete the default text "AI CH 1 – Fault" and enter new description "AI CH 1 – Over-Range", then press the 'OK' button to save and accept the new description. The text in this field is what will appear on the Alarm & Event Page when this fault is triggered.

As can be seen below, the Fault description has been changed. Now the Fault 1 red band needs to be moved to cover the range from above 20mA to 22mA. To achieve this two value's need to change, the 'Fault Trigger Setpoint' and the 'Fault Trigger Bandwidth'. The 'Fault Trigger Setpoint' value needs to be 21mA and the 'Fault Trigger Bandwidth' value needs to be 1mA. First of all, press the 'Change' button in the 'Fault Trigger Setpoint'.

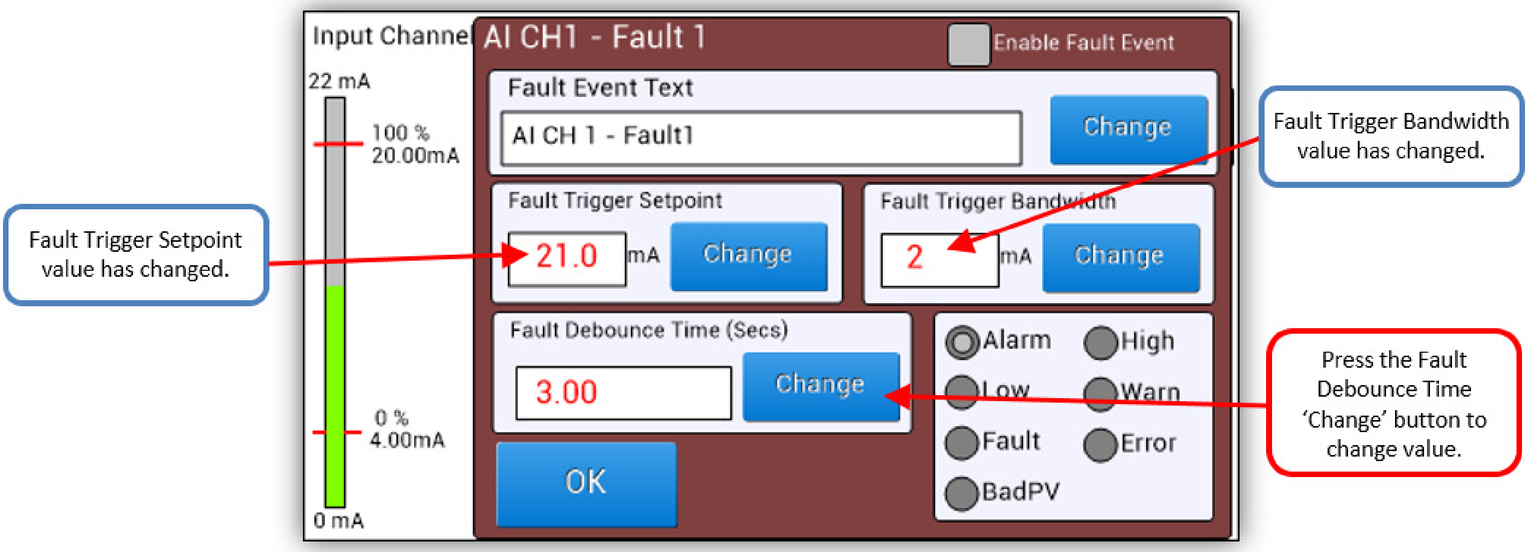


The Keyboard screen shall appear again, notice that the alphabetical letters are greyed out as these cannot be used when entering numerical values. Use the 'Backspace' key to delete the default value of "3.50" and enter new value "21.0", then press the 'OK' button to save and accept the new 'Fault Trigger Setpoint' value, as shown below.

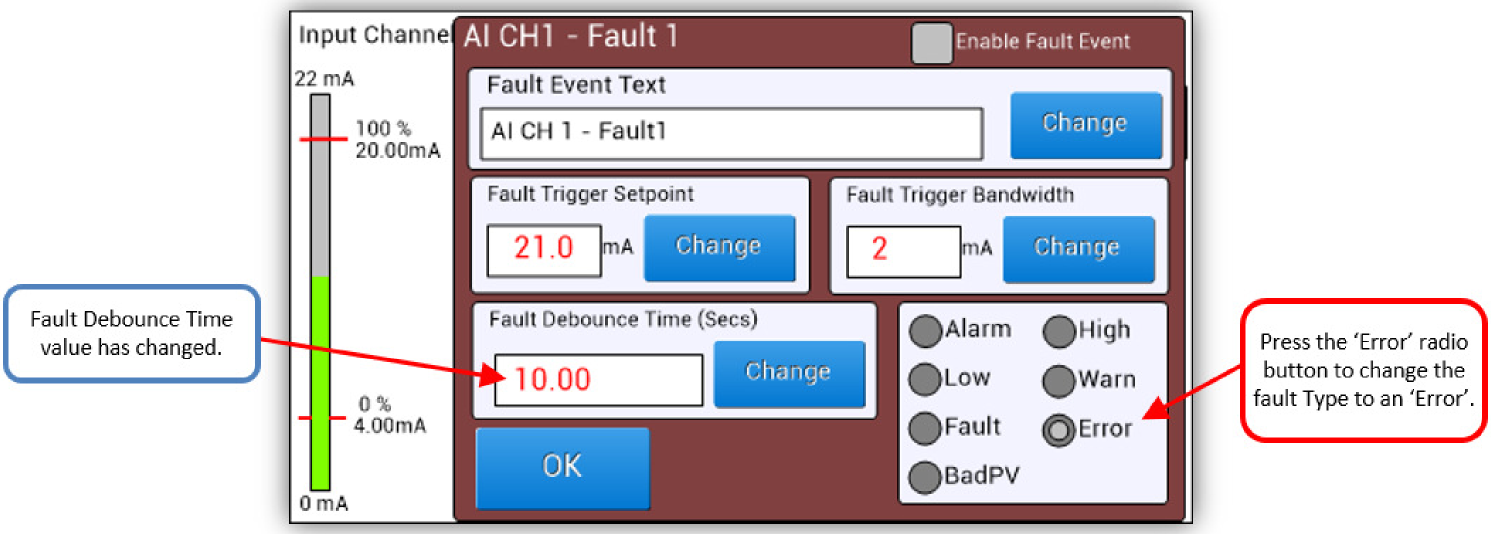


Do the same thing to change the 'Fault Trigger Bandwidth' by pressing its corresponding 'Change' button and changing its value, on the 'Keyboard' screen, to '2.00'. Then press the 'OK' button as before.

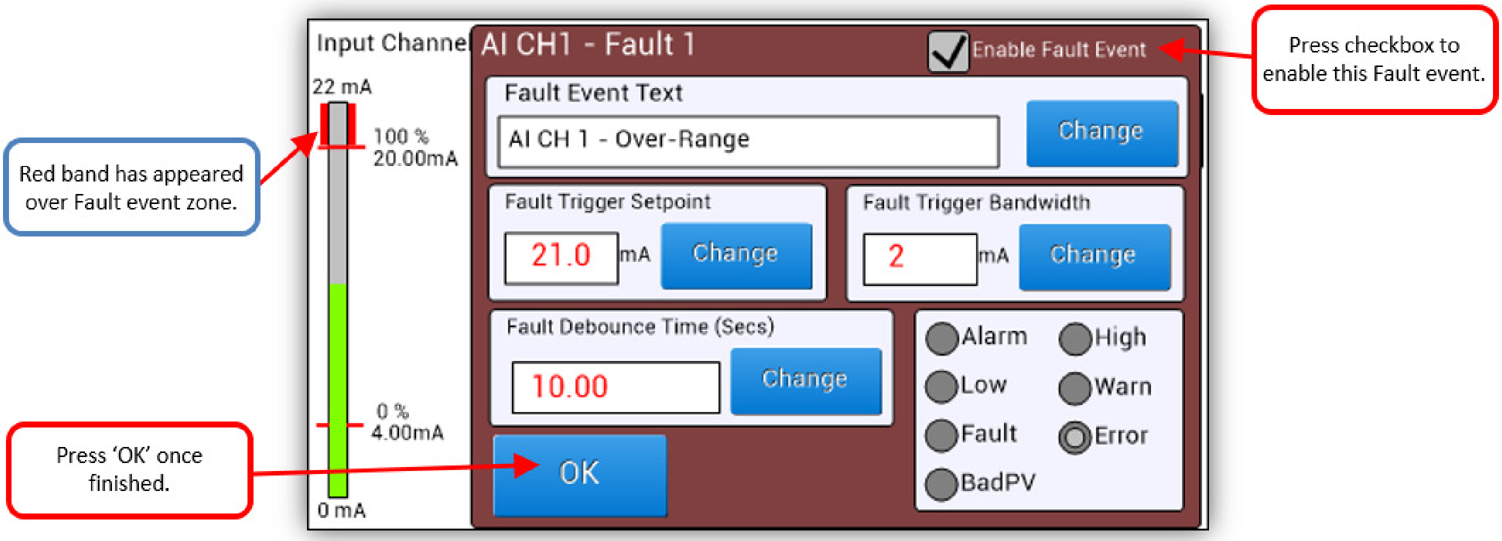
For this example, we don't want the AP-100 device to generate nuisance Fault event for if the connected instrument drifts above 20mA for a very brief period. To stop this, we can increase the 'Fault Debounce Time' to 10 seconds. This will mean that the AP-100 device will only generate a Fault event if the connected instrument drifts above 20mA for a full 10 seconds or more. To change the 'Fault Debounce Time' press the corresponding 'Change' button and enter the new value of 10 seconds.



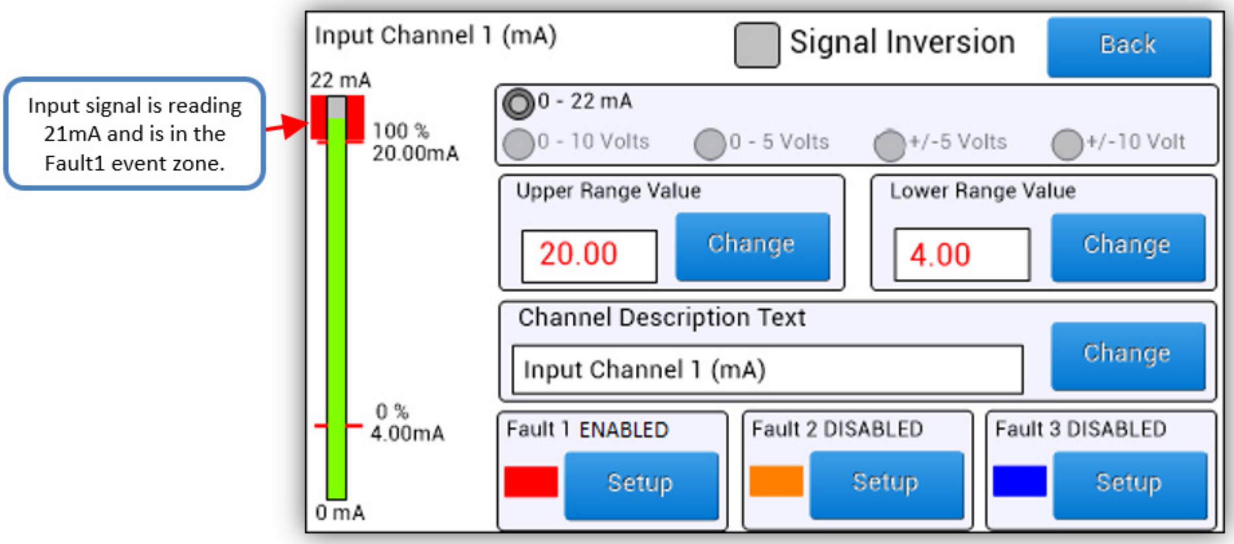
As discussed later in the Alarm & Events section, an event can have a category type assigned to it. This makes it easier to sort or filter Alarm & Events in a spreadsheet once downloaded from the AP-100 device. In this example we shall set this Fault event type to be 'Error' by selecting the 'Error' radio button as shown below.



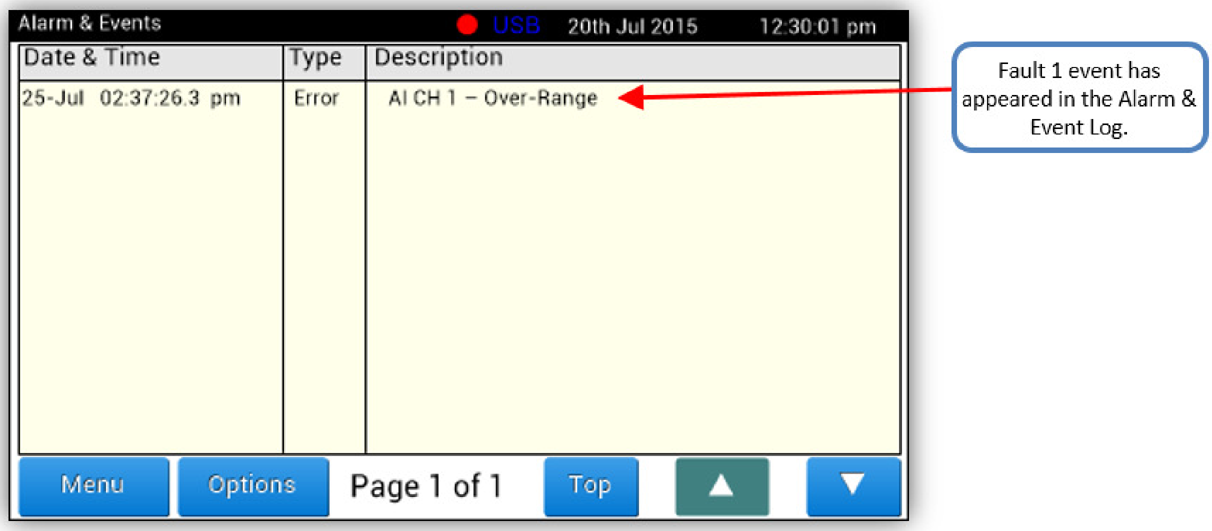
This Fault 1 event has now been configured. To enable this Fault 1 event, press the 'Enable Fault Event' checkbox on the top right. Notice that a red band has appeared over the signal ranged that the Fault event has been setup for.



Fault 1 is now configured and enabled and the screen shall look like the below. For this example, the input signal has been made to be 21mA, as shown below. Notice that the bar graph has increased and is now within the Fault 1 event zone. If the input signal should stay in this zone for 10 seconds (as configure above) or more, the Fault 1 event with text "AI CH 1 – Over-Range" shall appear in the Alarm & Events Log.



As is shown below, the Fault 1 event has appeared in the Alarm & Event Log with a time and date stamp. Notice that the event type is Error as configure above.

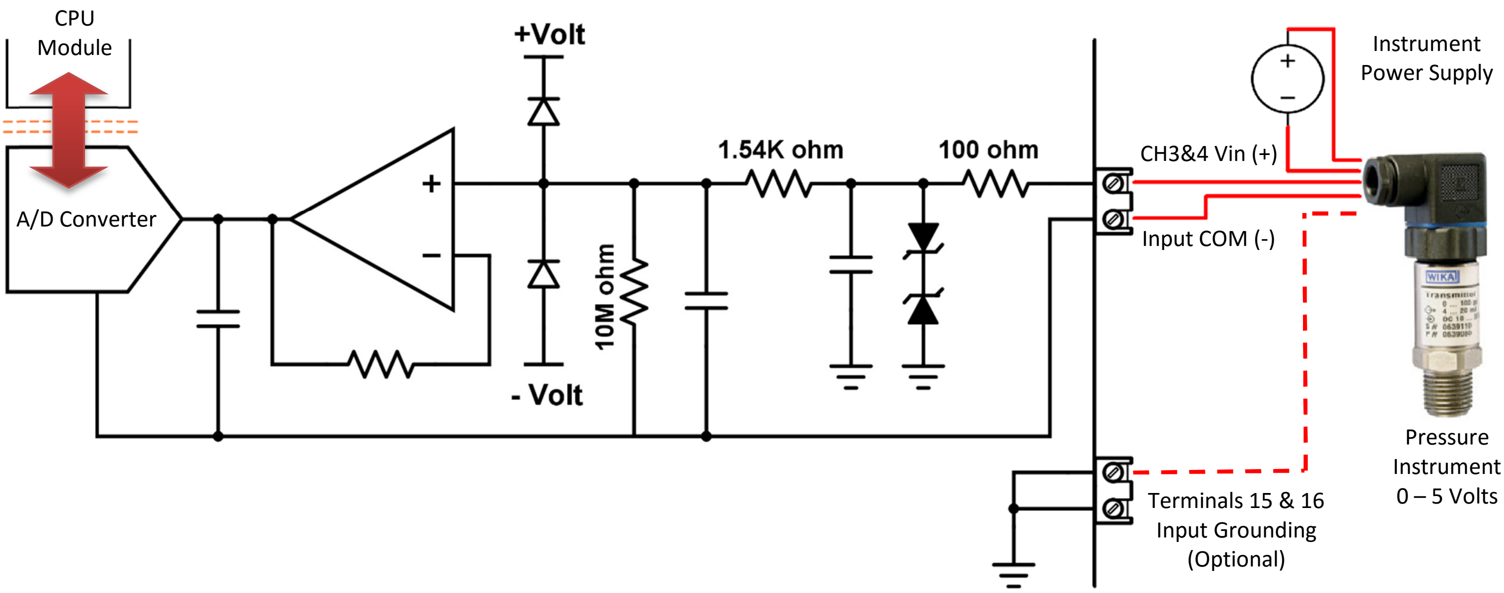


4.2. Analogue Input (Volts) Channels 3 & 4 Setup

The AP-100 Advanced Process Controller has two channels (CH3 & 4) that read Volt signals and is designed for the most demanding industrial control applications. These inputs have been designed with the following features:

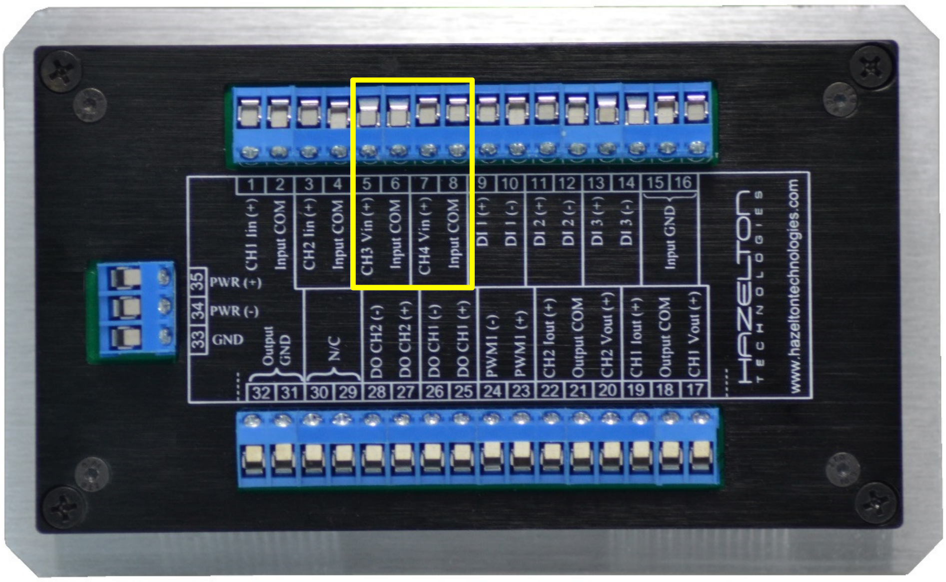
- CPU scans these inputs 100 times per second (every 10mS).
- Read Volt signals with a selectable upper and lower ranges of any value between -10 to +10 Volts.
- Each input channel has a resolution of 0.02 % over full range.
- Each input channel has a 1500-volt isolation from the CPU module, outputs channels and power supply.
- Each channel has over voltage and over current protection.
- Excellent signal to noise ratio including 50/60 Hz waveform cancelation.
- All input channels are designed to be external powered to give greater design flexibility.
- All channel settings data is stored in non-volatile memory and will remain after power off.

The below diagram shows the internal circuitry of the Analogue Input (Volts) Channels and recommended connection wiring diagram.



4.2.1. Electrical Terminals

The Analogue Input (Volts) Channels 3 & 4 terminals are highlighted below.



4.2.2. Range Setup

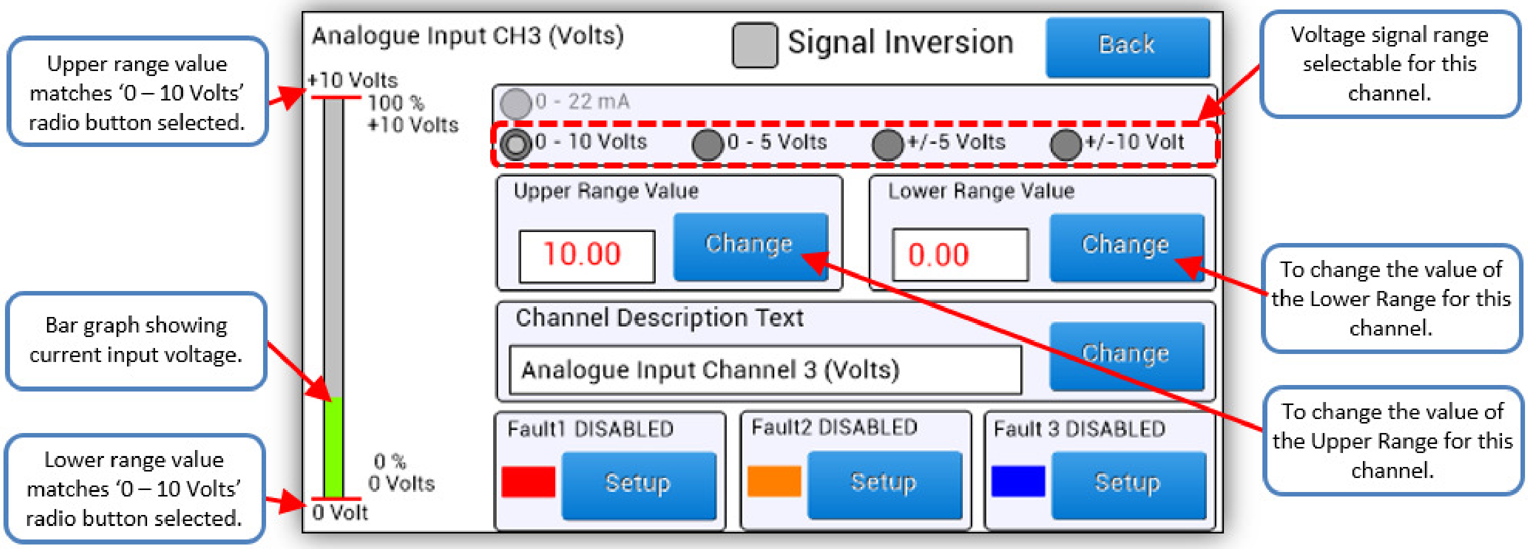
Below shows the setup screen for the Analogue Input Channel #3. This screen is identical to Analogue Input Channel #4 and therefore this following information applies to both Channels #3 and #4.

The full range of the Channels #3 and #4 is from -10 Volts to +10 Volts. Hence, the '0 - 22 mA' radio button is disabled and greyed out in the top box on the screen, these changes read Voltage signals only.

Analogue Input Channel's 3 & 4 register within the AP-100 device as decimal number between 0.000% to 100.000%.

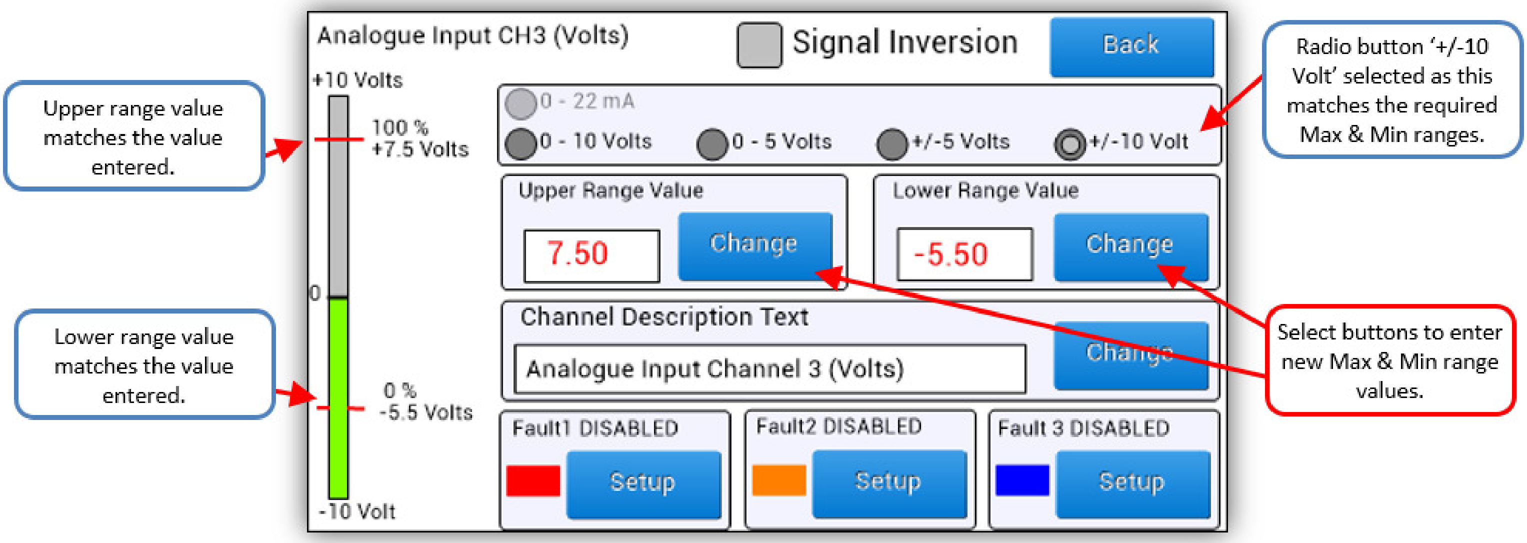
To set which upper range mA value will translate to 100.000%, press the corresponding 'Change' button in the 'Upper Range Value' field and enter the desired value. To set which lower range Voltage value will translate to 0.000%, press the corresponding 'Change' button in the 'Lower Range Value' field and enter the desired value.

As stated in the above section the resolution of these input channels is 0.02 % over full range. Therefore, to obtain the maximum resolutions it is best to select the radio button with the smallest range of this channels setup. For example, if the required max and min ranges were +4.5V and -1.5V respectively, then the '+/- 5 Volts' radio button should be selected for the best signal resolution.



Example

In the following example will show how to setup CH3 to have a maximum range of +7.5 volts and a minimum range of -5.5 volts. First select the '+/-10 Volt' radio button as this is the range that best suits the requirements for this example. Then select the respective 'Change' buttons to change the 'Upper Range Value' and 'Lower Range Value'. Once the values have been updated notices that the ranges on the bar-graph on the left have been updated.



Warning

- Before making setting changes to an online system first consider how this change effects associated outputs.
- It may be necessary to shutdown plant or equipment before making this change.

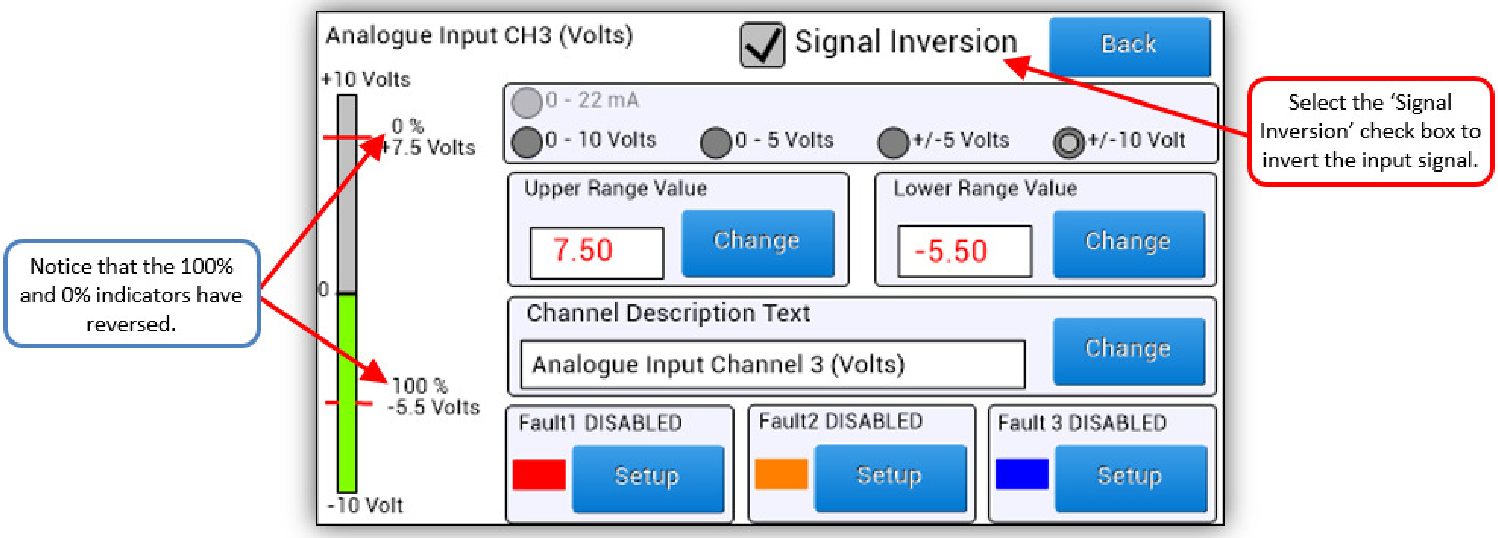
4.2.1. Description

To change the Input Channel's Description, press the corresponding 'Change' button and entered the desired description text for this channel, as shown in the above figure.

4.2.2. Signal Inversion

Notice in the above screen the large 'Signal Inversion' checkbox is un-checked and therefore the higher Voltage range value of +7.5 Volts corresponds to the 100% value and the lower Voltage range value of -5.5 Volts corresponds to the 0% value.

The below screen now has this 'Signal Inversion' checkbox active. Now the input signal has been inverted and the higher mA range value of +7.5 Volts corresponds to the 0% value and the lower mA range value of -5.5 Volts corresponds to the 100% value.



Warning

- Before making setting changes to an online system first consider how this change effects associated outputs.
- It may be necessary to shutdown plant or equipment before making this change.

4.2.3. Signal Fault Event Setup

Setting up a fault event for Channels #3 and #4 is the same as for Channels #1 and #2, see section 4.1.4 for full details. The only difference is that all values are in Volts.

Warning

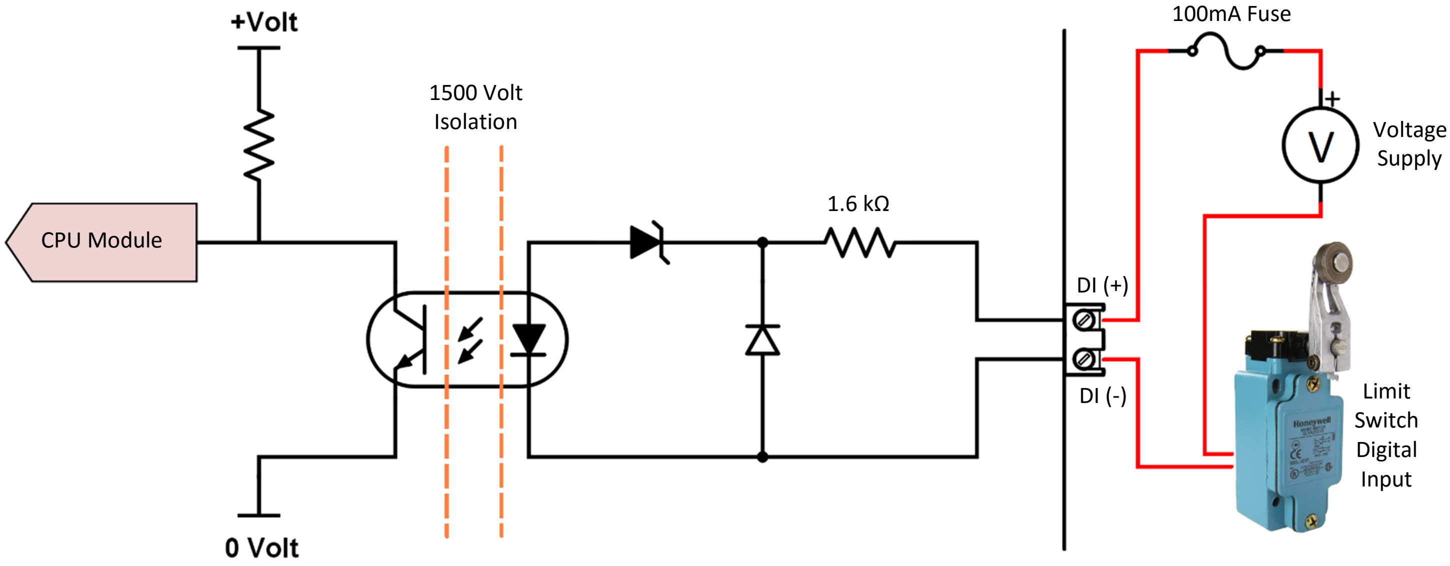
- All Fault events shall be disabled if a Range radio button is changed.

4.3. Digital Inputs Setup

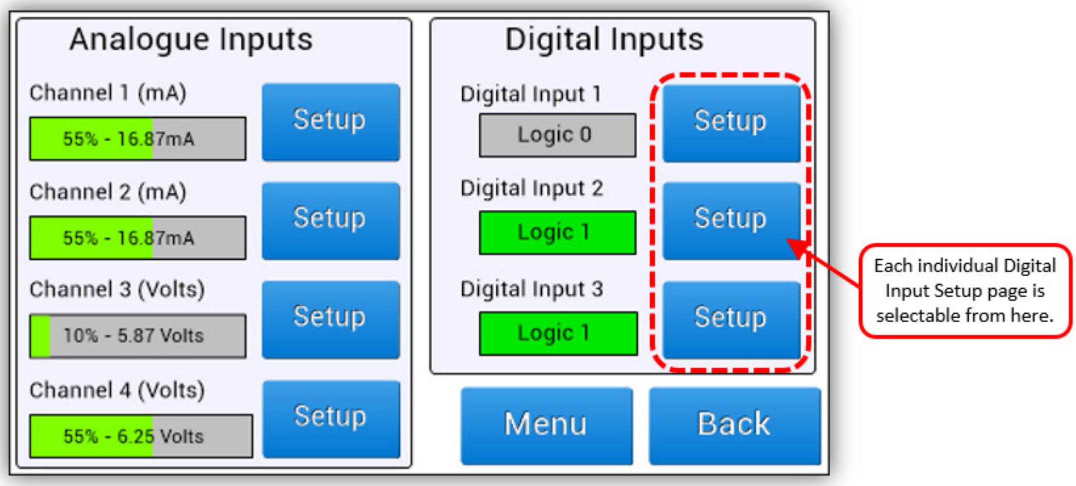
The AP-100 Advanced Process Controller has three channels (CH1, 2 & 3) that read Digital Volt signals. These inputs have been designed with the following features:

- CPU scans these inputs 100 times per second (every 10mS).
- Free-wheel diode for reverse polarity protection.
- Direct Current (DC) digital input only.
- Logical '1' voltage range: Maximum = 32 V_{DC}, Minimum = 10 V_{DC}.
- Logical '0' voltage range: Maximum = 6 V_{DC}, Minimum = 0 V_{DC}.
- 100mA inline fuse is recommended.

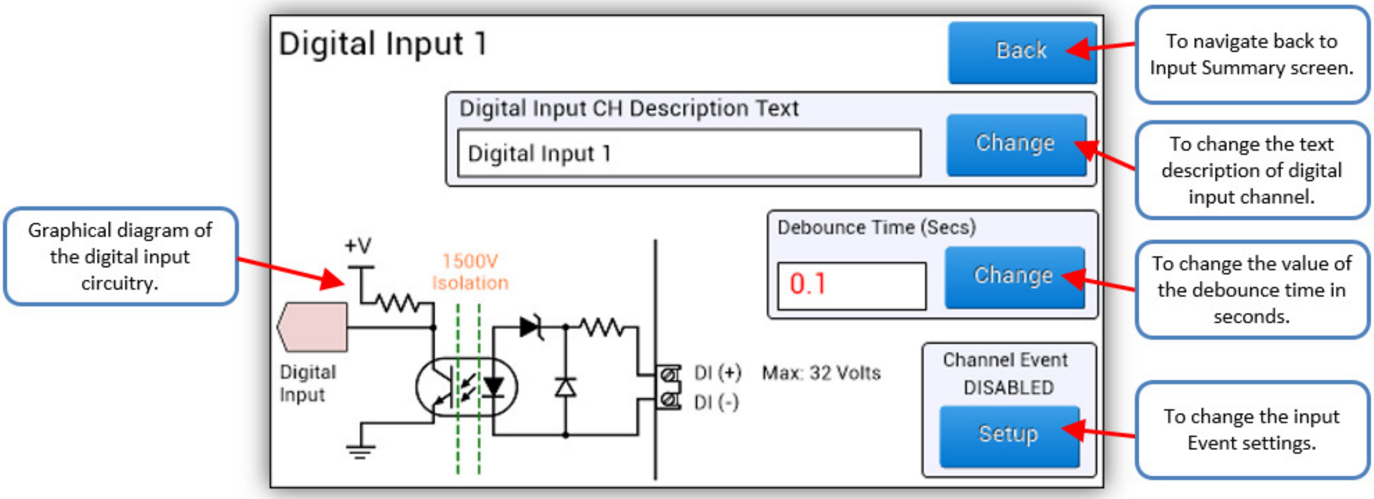
The below diagram shows the internal circuitry of the Digital Input Channels and recommended connection wiring diagram.



Below shows the 'Input Channels Setup' menu screen. This screen is reachable from the 'Main Menu' by pressing the 'Settings' icon and then pressing the 'Input Channels Setup' icon. This screen is used to navigate to the setup of each Input channels. Each of the three Digital Inputs Channel settings can be accessed by

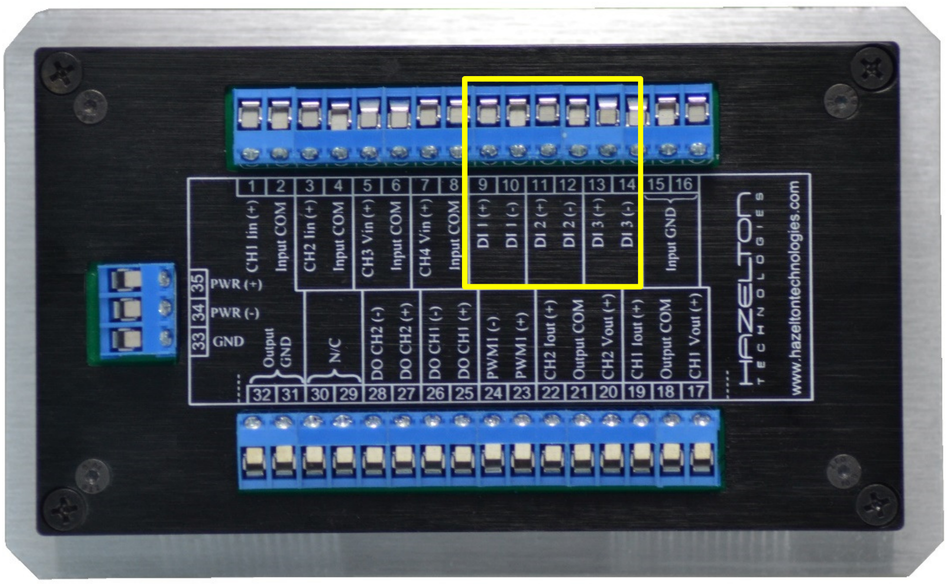


Below is the Digital Input CH #1 screen. This screen has the same layout and setup procedure for all three digital Input Channels #1, #2 and #3.



4.3.1. Electrical Terminals

The Digital Inputs terminals are highlighted below.



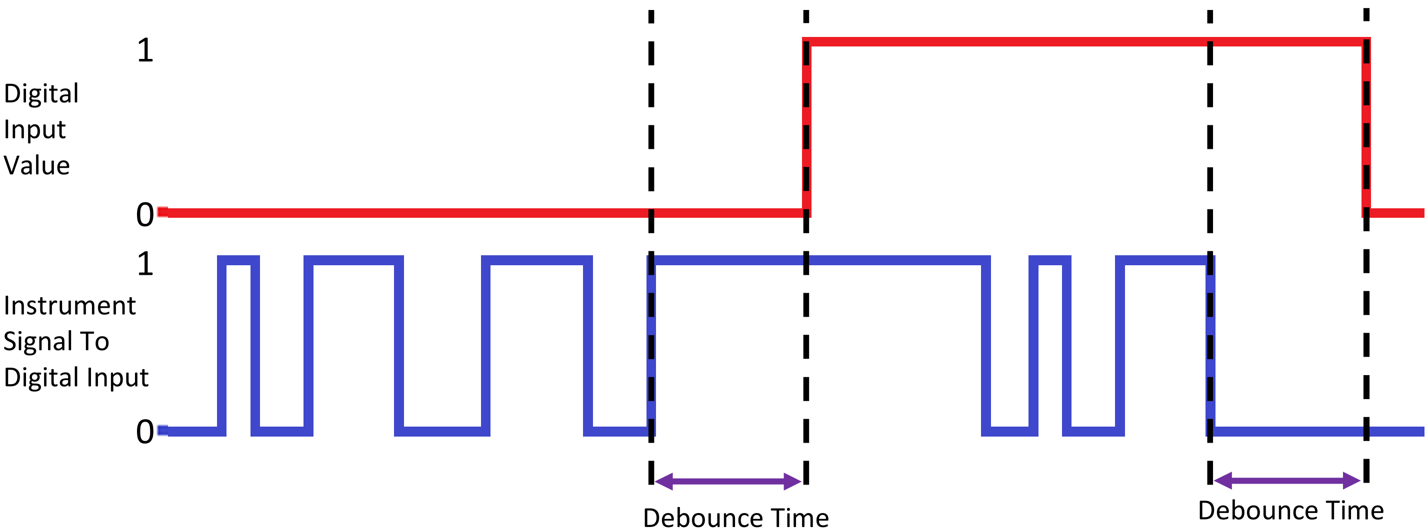
4.3.2. Channel Description

As indicated above, to change the Digital Input description text, press the corresponding 'Change' button and enter in the new text description, as shown below.

4.3.3. Debounce Time

All three Digital Input channels have a user configuration debounce time. This means that if the 'Debounce Time' is set to 0.1 seconds (as shown above) for a give digital input channel, and the current logical input state it '0'. Then the Digital Input would have to transition to the logical '1' state for a full 0.1 seconds before the CPU module will register this input state as logical '1'. This is the same for the converse when transitioning from logical '1' to logical '0'.

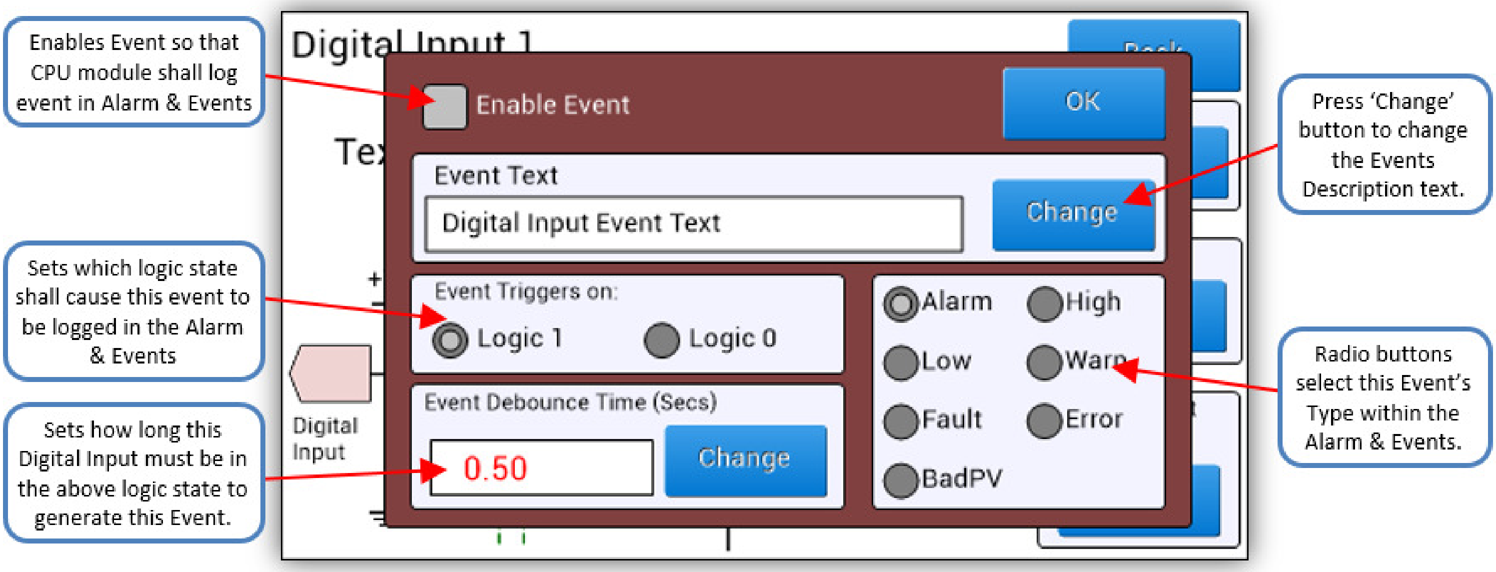
This is depicted in the below timing diagram of the Digital Input's logic state vs the signal sent to the Digital Input channel.



4.3.4. Event Setup

A Digital Input can be setup to generate an Event for a particular input logic state. This is useful for recording real-world events in real-time (see Alarm & Event section for more information on events).

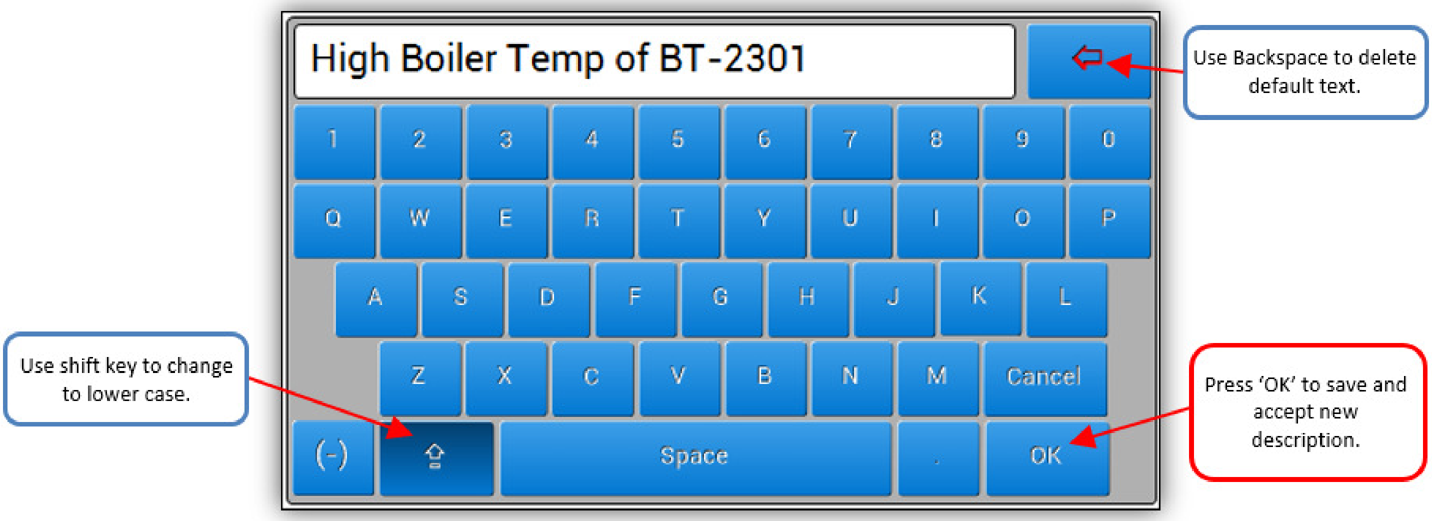
As shown indicated above, the Event Setup dialog box can be displayed by pressing the corresponding 'Setup' button in the 'Channel Event' field. The Event Setup dialog box is shown below.



Example

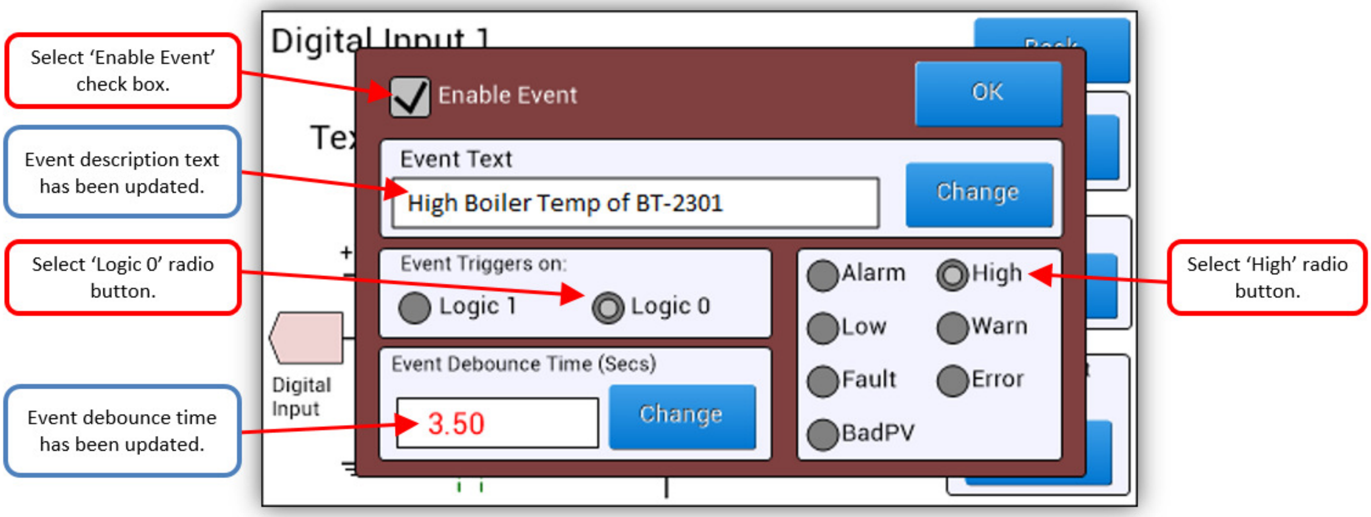
In the following example it shall be assumed that there is a boiler High Temperature Switch connected to Digital Input Channel #1. When the temperature switch is active logical '0' (Safe state is logical '1'). When the High Temperature Switch is active for 3.5 seconds or more, the event with description text "High Boiler Temp of BT-2301" shall be logged in the Alarm & Events page with Type of 'High'.

Firstly, press the corresponding 'Change' button in the 'Fault Event Text' field to display the keyboard screen as shown below. Use backspace to delete the existing text and then enter the text "High Boiler Temp of BT-2301".

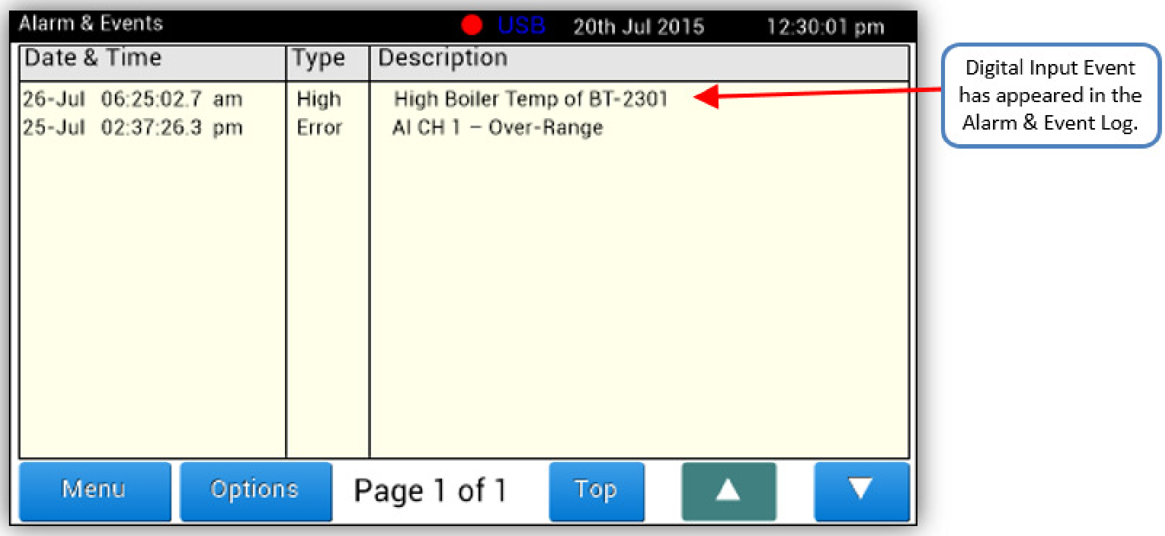


Then press 'OK' to save and accept the new description text. Once returned to the previous Event Setup screen, press the 'Change' button that corresponds to the 'Event Debounce Time (Secs)' field. This will display the numbers keyboard, use backspace to delete the default value, then enter the new value of "3.5" seconds, as shown below. Then press 'OK' to save and accept.

Select the 'Logic 0' and 'High' radio buttons, and then enable this event by selecting the 'Enable Event' check box, as shown below.

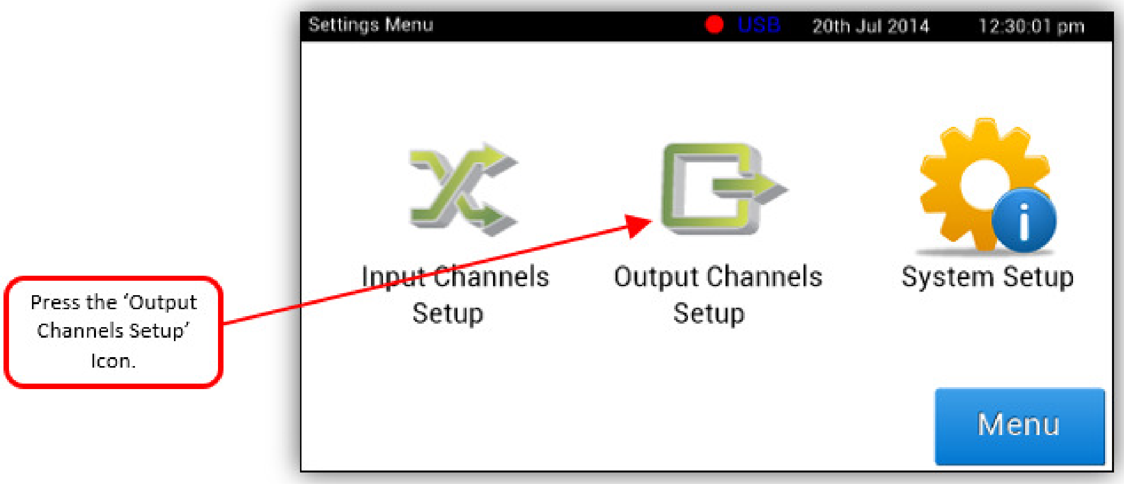


Now the Digital Input CH #1 event has been enabled. If the Digital Input CH #1 input signal goes to logical '0' for 3.5 seconds or more, an event with text description shall be logged in the Alarm & Events Log as shown below. See the Alarm & Events sector for instruction on how to download the Alarm & Events Log onto a USB memory stick to be viewed in a spreadsheet (such as MS Excel).


Alarm & Events
USB
20th Jul 2015
12:30:01 pm
Date & Time
Type
Description
26-Jul 06:25:02.7 am
High
High Boiler Temp of BT-2301
25-Jul 02:37:26.3 pm
Error
AI CH 1 – Over-Range
Menu
Options
Page 1 of 1
Top
Digital Input Event has appeared in the Alarm & Event Log.

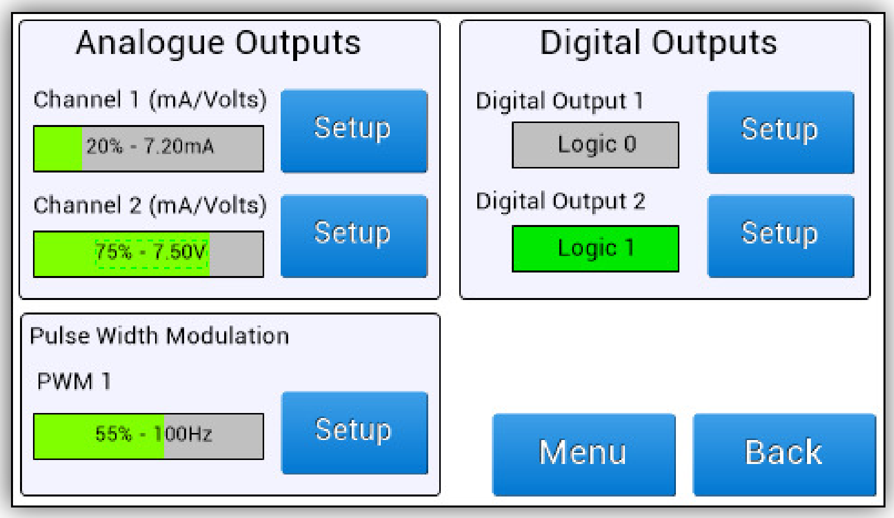
5. ANALOGUE & DIGITAL OUTPUT CHANNELS SETUP

To navigate to the Analogue & Digital Output Channels summary, firstly press the 'Settings' icon on the Main Menu to display the 'Settings Menu' screen as shown below. From here the user can navigate to setup analogue and digital signal Inputs and Outputs. Also internal settings can be changed such as the time and date. Press the 'Input Channels Setup' icon to display all input channels and settings.



Below shows the 'Output Channels Setup' menu screen. This screen is used to navigate to the setup of each Output channel. The user can also use this screen to easily view the current values of the analogue and digital output channels. These outputs were designed for the most demanding industrial control applications. See 'Equations Setup' Section 6 for details as to how to write to output channels. As shown below, the output channels available on the AP-100 Advanced Process Controller are:

- Two Analogue Output channels that can be configured as either:
  - a) Voltage (0-10Volts, 0-5Volts, +/-5Volts & +/-10Volts), or
  - b) mA (0-22mA, 0-20mA & 4-20mA) outputs.
- Two Digital Relay Output Channels (230Vac / 2 Amps).
- One Pulse Width Modulation Output (1Hz to 1000Hz).

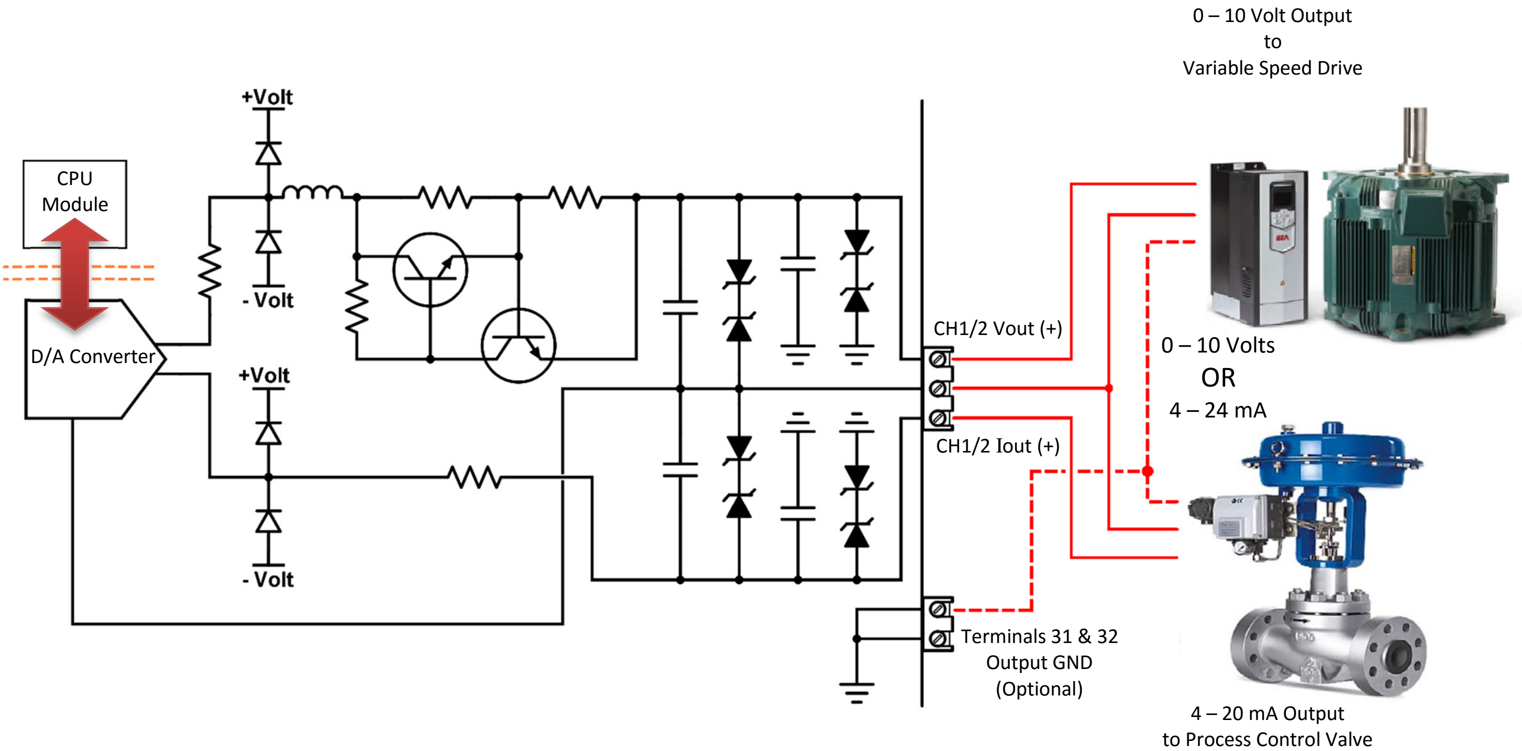


5.1. Analogue Output Channels Setup

The AP-100 Advanced Process Controller has two channels (CH1 & 2) that are configured as either Voltage (0-10Volts, 0-5Volts, +/-5Volts & +/-10Volts) or mA (0-24mA, 0-20mA & 4-20mA) outputs. These Outputs have been designed with the following features:

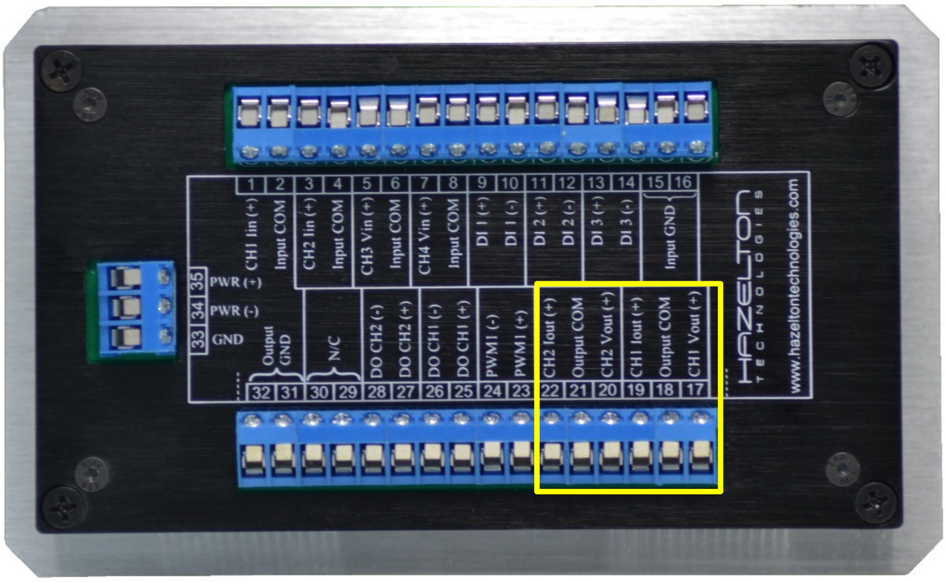
- CPU updates these outputs 100 times per second (every 10mS).
- Output signals with a selectable upper and lower ranges of any value between 0 to 22mA or 0 to 10 Volts.
- Each output channel has a resolution of 0.005 % over full range.
- Each output channel has a 1500-volt isolation from the CPU module, inputs channels and power supply.
- Each channel has over voltage and over current protection.
- Excellent signal to noise ratio including 50/60 Hz waveform cancelation.
- All output channels are designed to be internal powered to give greater design flexibility.
- All channel settings data is stored in non-volatile memory and will remain after power off.
- 50mA in line fuse is recommended.

The below diagram shows the internal circuitry of the Analogue Input (Volts) Channels and recommended connection wiring diagram.



5.1.1. Electrical Terminals

The Analogue Output Channels 1 and 2 terminals are highlighted below.

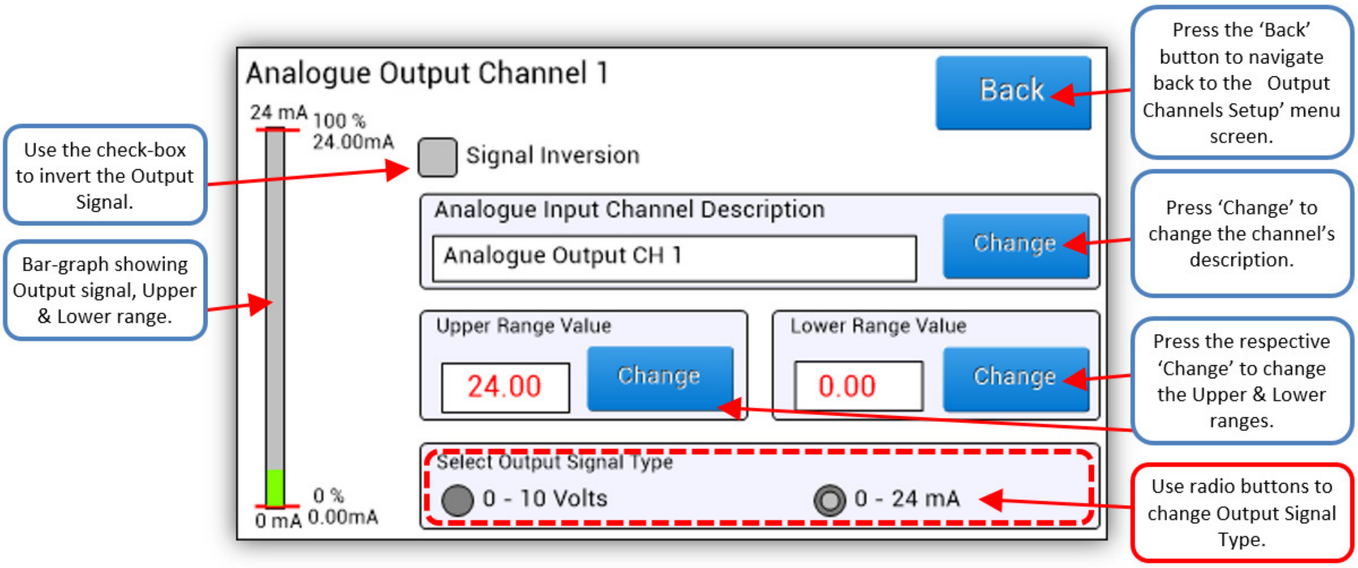


5.1.2. Analogue Output Signal Type

The setup page for Analogue Output Channels is shown below. The setup for both Analogue Output Channels #1 and #2 is the same procedure, so for the follow shall show examples for Channel #1 only. As stated above the two Analogue Output Channels are able to output signals of type 0 – 10 Volts or 0 – 24 mA.

To set Output Channel setup the output as 0 – 24 mA, press the corresponding radio button as shown below. Then a mA current signal driven device can be connected to terminals 19 (CH1 Iout(+)) and 18 (Output COM(-)) for Channel #1 and terminals 22 (CH2 Iout(+)) and 21 (Output COM(-)) for channel #2.

To set Output Channel setup the output as 0 – 10 Volts, press the corresponding radio button as shown below. Then a voltage signal driven device can be connected to terminals 17 (CH1 Vout(+)) and 18 (Output COM(-)) for Channel #1 and terminals 20 (CH2 Vout(+)) and 21 (Output COM(-)) for channel #2.



5.1.3. Description

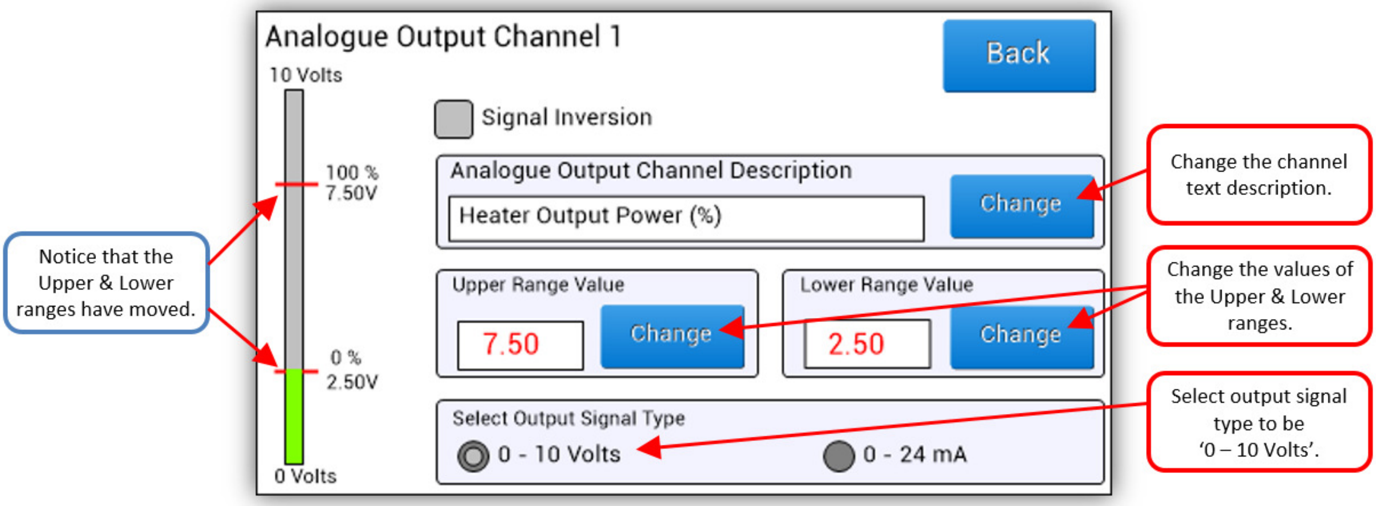
To change the Input Channel's Description, press the corresponding 'Change' button and entered the desired description text for this channel, as shown in the above figure.

5.1.4. Range Setup

The Upper and Lower range can be easier set to the user's requirement by first selecting the output signal type as shown above and then pressing the respective Upper and Lower 'Change' buttons and entering the desired value.

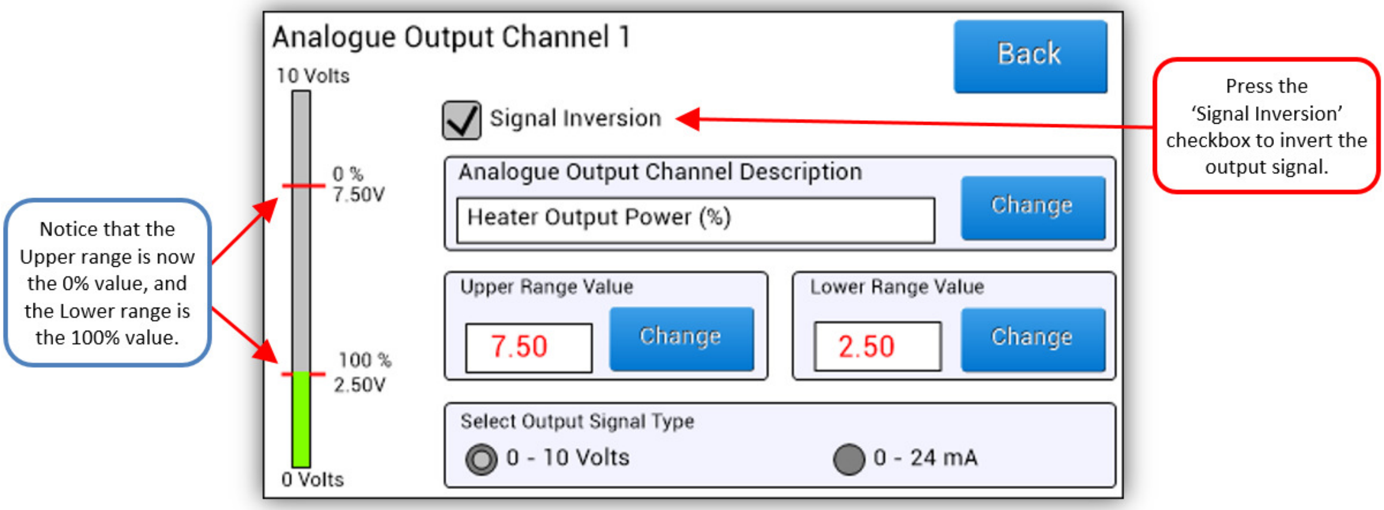
Example

The Analogue Output Channel #1 is to be connected to a Silicon Controller Rectifier (SCR) that is driving an electric heater for a plastics injection moulding heater. The SCR requires a control signal of Upper range (100%) of 7.50 volts and a lower range (0%) of 2.50 volts. Then to change the channel's description pressing the corresponding 'Change' button and enter new description "Heater Output Power (%)".



5.1.5. Signal Inversion

In the above example, to invert the output signal to that the new Lower range is 7.50 volts and the new Upper range is 2.50 volts, simply press the 'Signal Inversion' checkbox as shown below.



Warning

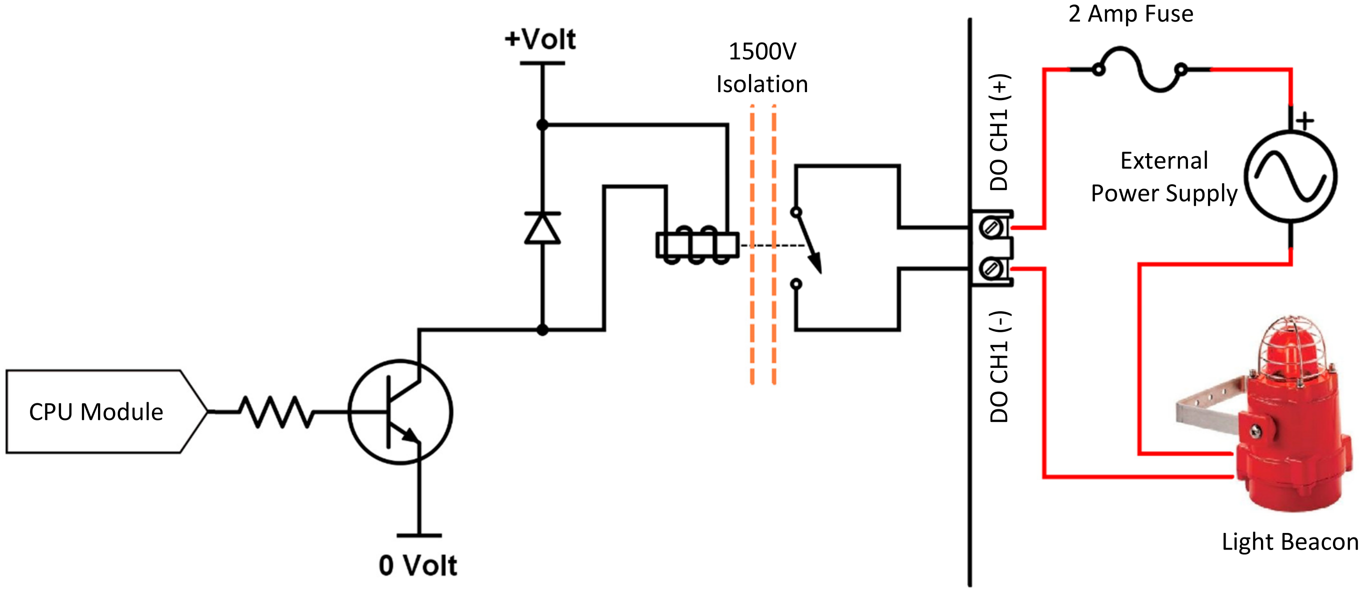
- Before making setting changes to an online system first consider how this change effects associated outputs.
- It may be necessary to shutdown plant or equipment before making this change.

5.2. Digital Output Relays Channels #1 and #2

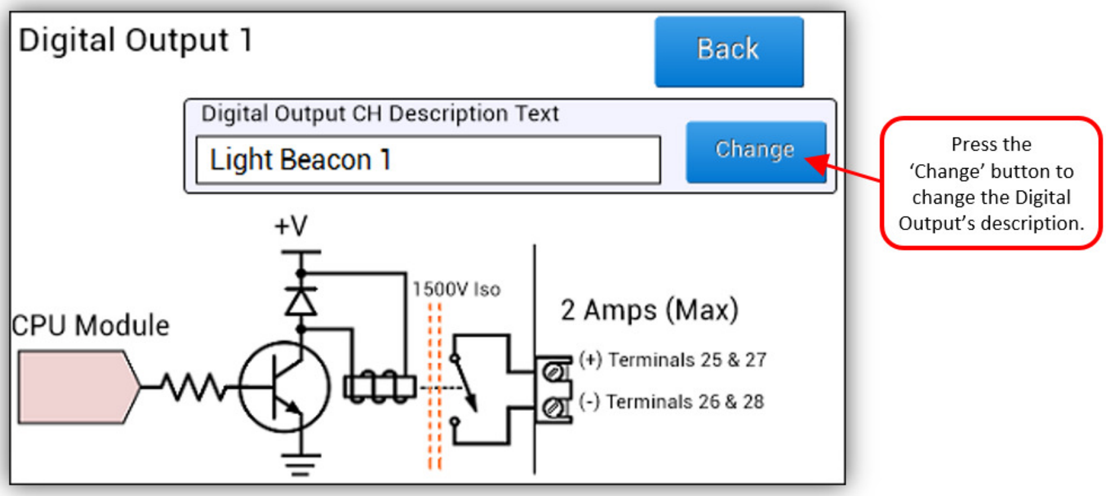
The AP-100 Advanced Process Controller has two output relay channels (CH1 & 2). These Outputs have been designed with the following features:

- CPU updates these outputs 100 times per second (every 10mS).
- Each output channel has a 1500-volt isolation from the CPU module, Inputs & Outputs channels and power.
- Each channel has over voltage and over current protection.
- 2 A in line fuse is recommended.

The below diagram shows the internal circuitry of the Digital Output Channels and recommended connection wiring diagram. In this example the digital output is being used to control a light beacon.

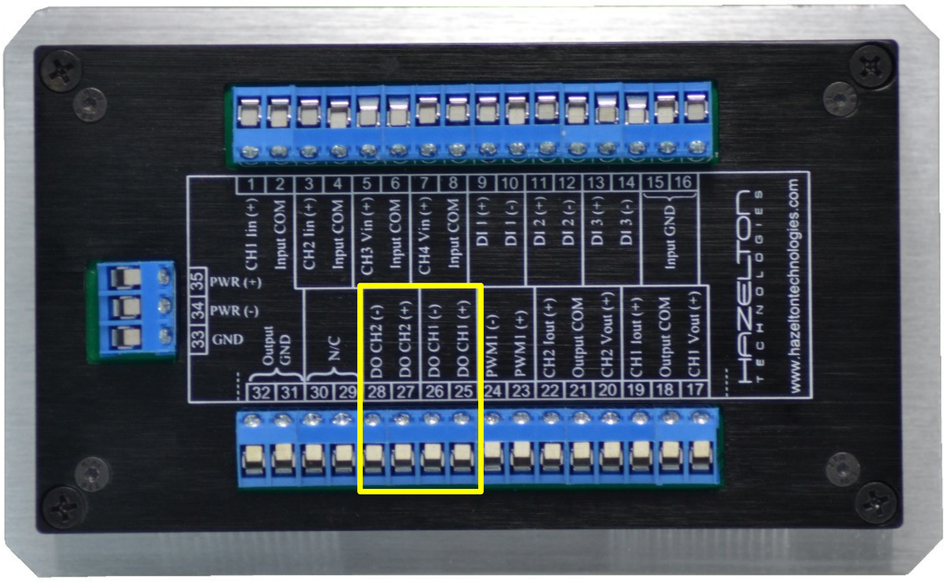


The AP-100 setup screen for Digital Output Channel #1 is shown below. The setup graphic for Digital Output Channel #2 is of the same layout.



5.2.1. Electrical Terminals

The Digital Output Relays Channels #1 and #2 terminals are highlighted below.



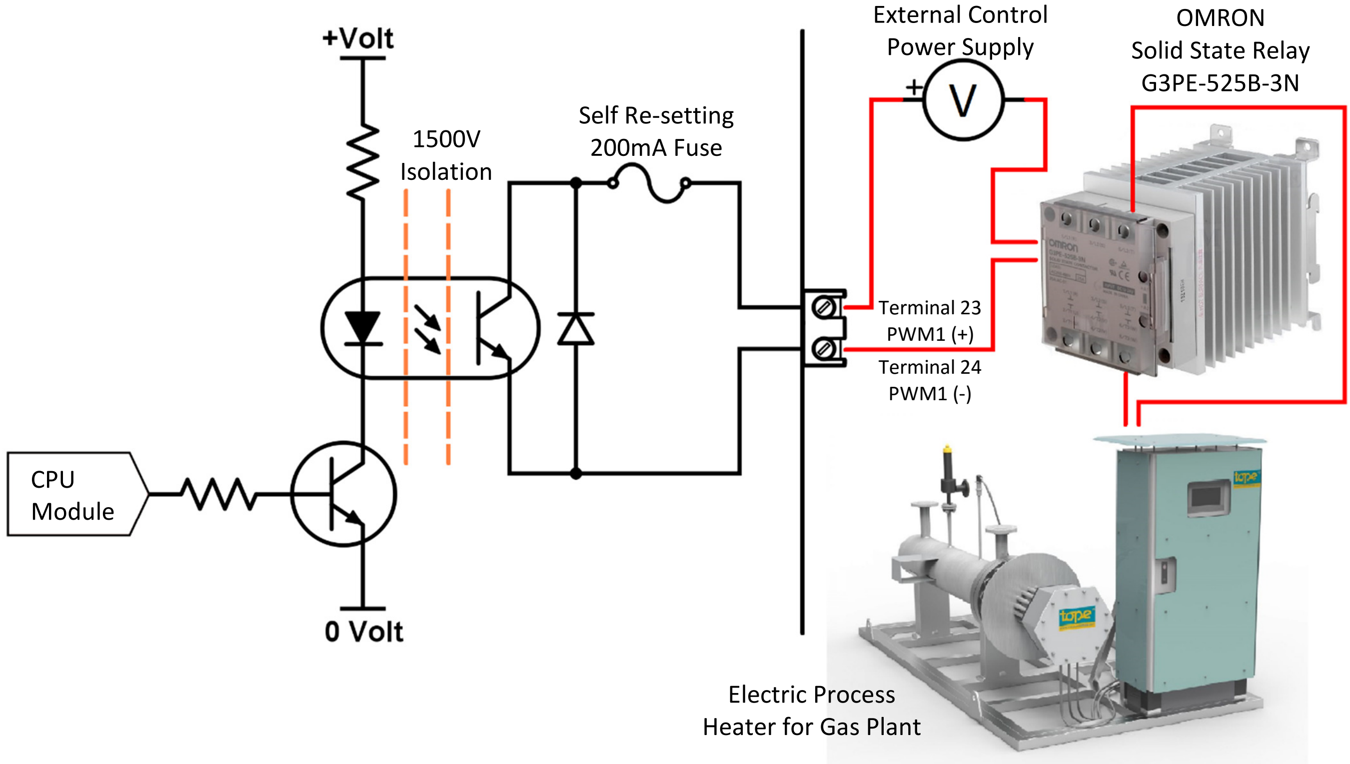
5.2.2. Description

To change the channel's description, press the corresponding 'Change' button and enter the desired text as shown above.

5.3. Pulse Width Modulation Output Channel Setup

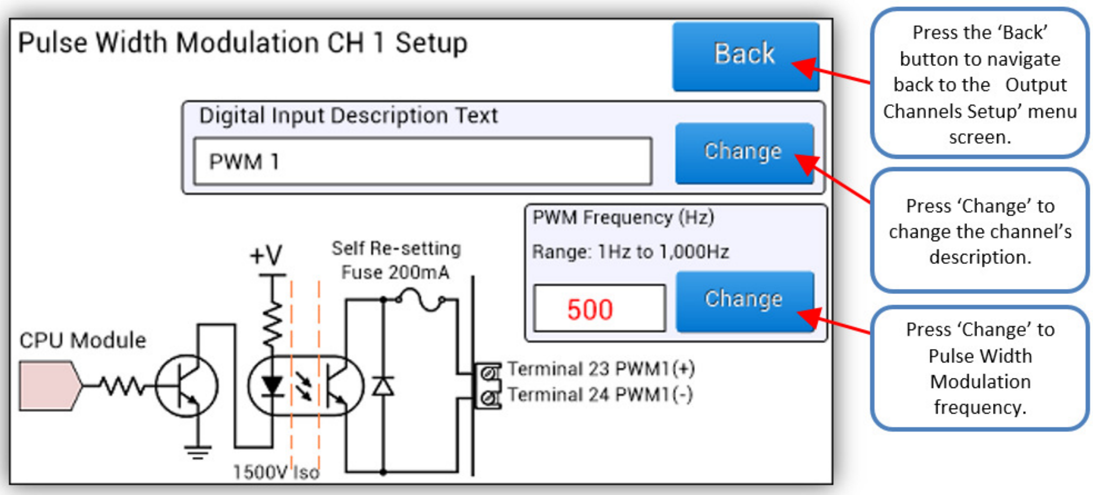
The AP-100 Advanced Process Controller has a signal Pulse Width Modulated (PWM) Channel that incorporates a photo-relay that can generate a square wave output. This Output has been designed with the following features:

- Range from 0.00% to 100.00% duty cycle, with user configurable frequency of 1Hz to 1000Hz.
- CPU updates these outputs 100 times per second (every 10mS).
- This channel has a 1500-volt isolation from the CPU module, Inputs & Outputs channels and power.
- Internal free-wheel diode to protect the channel from reverse polarity damage.
- Internal Self Re-setting Fuse (200 mA) – if fuse is tripped it shall re-set itself 30 seconds after power off.



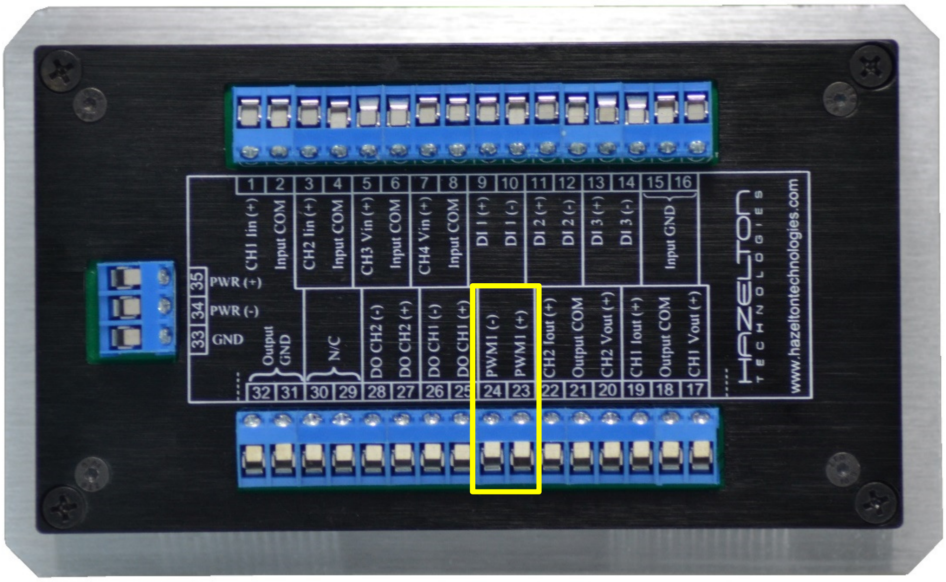
5.3.1. Description

The PWM's setup screen is as per the below. The channels description can be changed by pressing the corresponding 'Change' button.



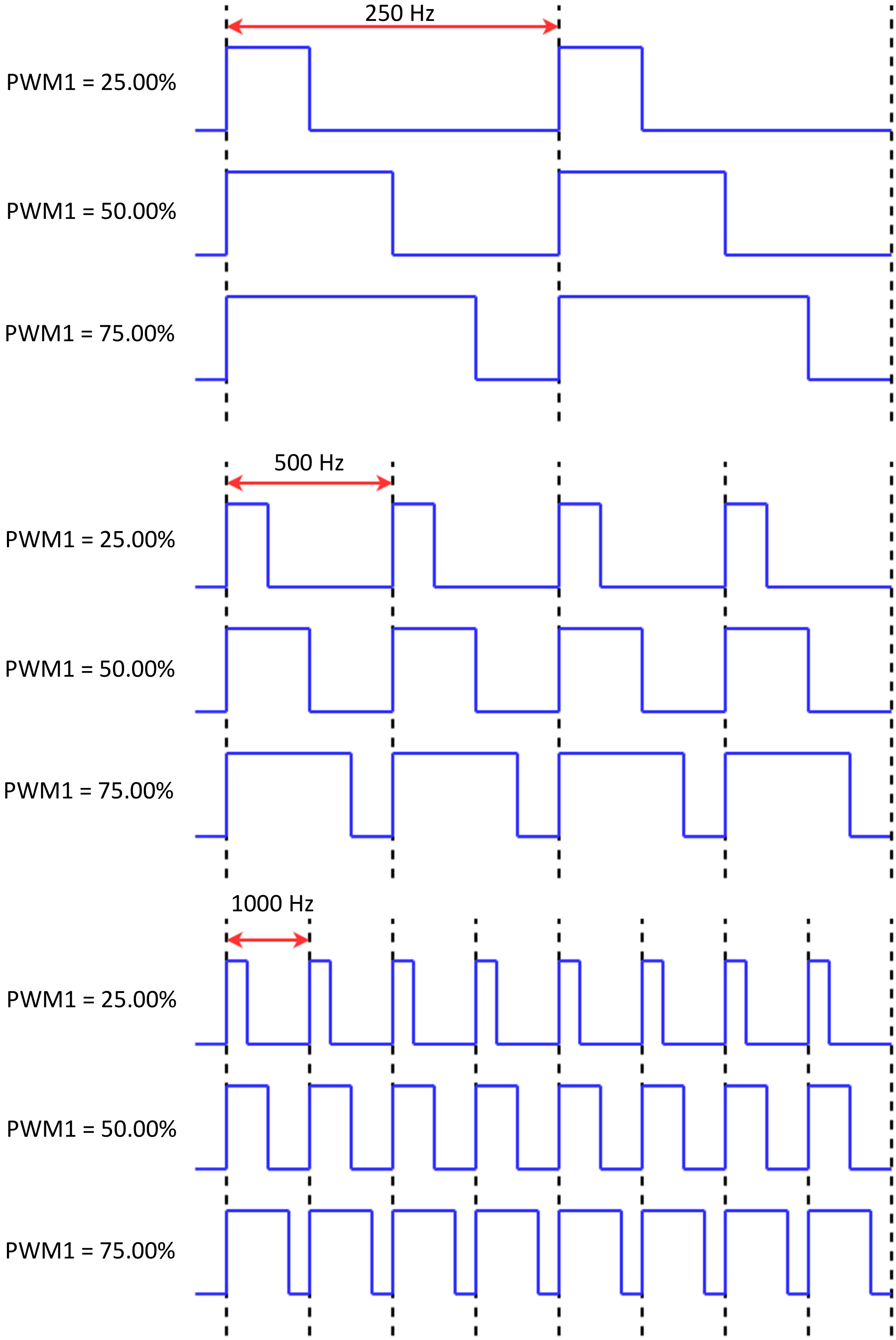
5.3.2. Electrical Terminals

The Pulse Width Modulation Output Channel terminals are highlighted below.



5.3.3. Frequency

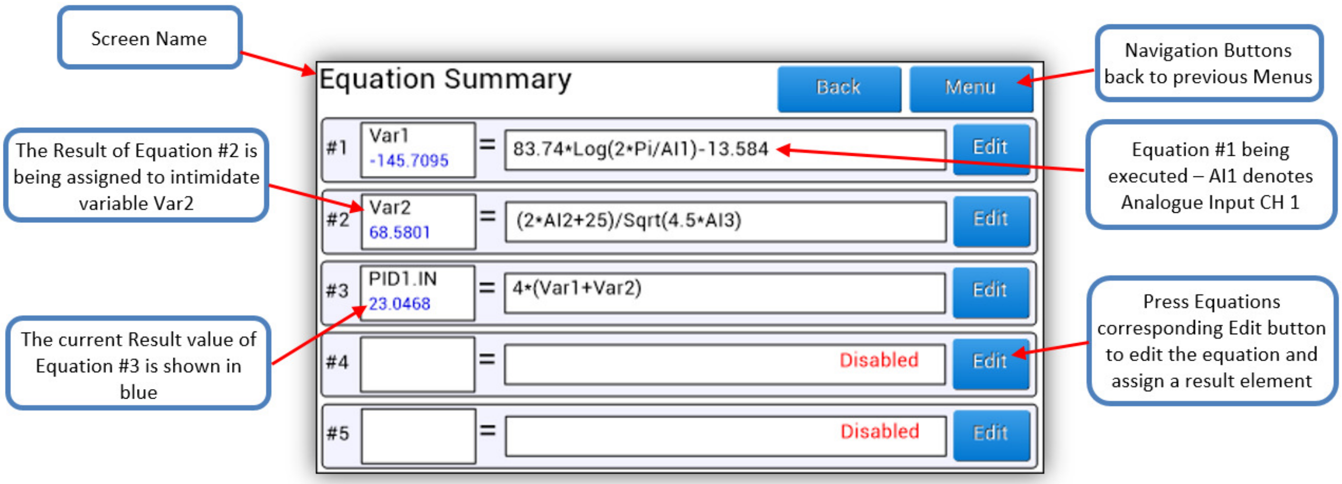
The frequency of the PWM1 output signal can be configured to any whole number value between 1 Hz to 1000Hz, simply be pressing the corresponding 'Change' button as shown above. The PWM1 output is a square wave with a variable duty from 0.00% to 100.00% as shown below.



6. EQUATION SETUP

The AP-100 is able to perform complex mathematical operations on digital and analogue inputs and outputs signals. The AP-100 is capable of executing up to 5 equations, 100 times a second (every 10mS). It should be noted that the all the AP-100 executes the following cycle every 10mS. First all analogue and digital inputs are scanned, then the Equations are executed starting with Equation #1 through to Equation #5. Then PID Controllers #1 and #2 are executed, then all analogue and digital outputs are updated.

Below shows the Equation Summary screen, with an example to illustrate its function. Equation results may equal digital or analogue Outputs or Intermediate Variables or PID Controller Inputs.



As seen above, Equation #1 has had the equation **"83.74 * Log (2 * Pi / AI1) - 13.584"** entered, whereby AI1 is the current value of Analogue Input Channel #1 and Pi equals 3.14159265359. The result of Equation #1 has been assigned to Intermediate Variable #1 denoted 'Var1'. The current value of Equation #1 is shown in blue below the assigned variable Var1.

Equation #2 has had the equation **"(2 * AI2 + 25) / Sqrt (4.5 * AI3)"** entered, whereby AI2 and AI3 are the current values of Analogue Input Channel #2 and Analogue Input Channel #3 respectively. The result of Equation #2 has been assigned to Intermediate Variable #2 denoted 'Var2'. The current value of Equation #2 is shown in blue below the assigned variable Var2.

Equation #3 has had the equation **"4 * (Var1 + Var2)"** entered, whereby Intermediate Variables Var1 and Var2 hold the latest values of Equations #1 and #2 respectively. The result of Equation #3 has been assigned to the Input of PID Controller #1. When PID Controller #1 is enabled and set to AUTO mode, it will read the current value of the result of Equation #3.

Below, Table 1 lists all of elements that may be used within equations. As shown in the column on the right, some elements such as digital or analogue Inputs are Read only. Whilst other elements such as digital or analogue Outputs can only be Written to. Intermediate Variables (Var1 to Var6) are special, as they can be any value and can be Written to and Read from.

Analogue Inputs and Outputs have maximum and minimum values of 100.000 and 0.000 respectively. Digital Inputs and Outputs have maximum and minimum values of 1 and 0 respectively. If a value is written to and element that is outside the maximum and minimum values the AP-100 device will make that element equal to its respective maximum and minimum value.

For example:

1) If the value of '2002.513' is assigned to 'AO2', then 'AO2' will become 100.000.
2) If the value of '-41' is assigned to 'DO1', then 'DO1' will become logical 0.
3) Note that if any positive value is assigned to a DO1 or DO2 (such as 0.25), then DO1 or DO2 will become logical 1.

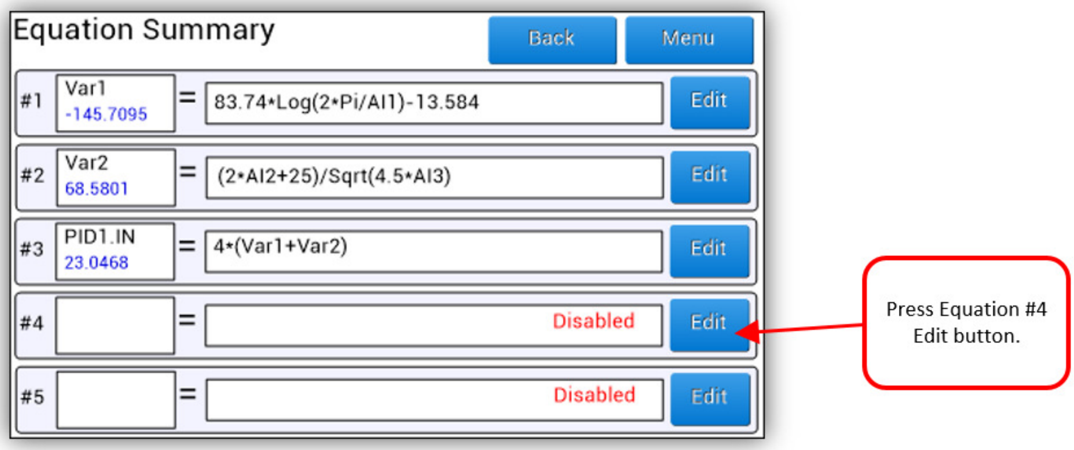
Table 1. Variable Elements that can be used in Equations.

Element	Description	Read/Write	Max Value	Min Value
AI1	Analogue Input Channel #1	Read	100.000	0.000
AI2	Analogue Input Channel #2	Read	100.000	0.000
AI3	Analogue Input Channel #3	Read	100.000	0.000
AI4	Analogue Input Channel #4	Read	100.000	0.000
DI1	Digital Input Channel #1	Read	1	0
DI2	Digital Input Channel #2	Read	1	0
DI3	Digital Input Channel #3	Read	1	0
PID1.IN	PID Controller #1 Input Channel	Write	100.000	0.000
PID1.SP	PID Controller #1 Set-Point	Write	100.000	0.000
PID1.OUT	PID Controller #1 Output Channel	Read	100.000	0.000
PID2.IN	PID Controller #2 Input Channel	Write	100.000	0.000
PID2.SP	PID Controller #2 Set-Point	Write	100.000	0.000
PID2.OUT	PID Controller #2 Output Channel	Read	100.000	0.000
DO1	Digital Output Channel #1	Write	1	0
DO2	Digital Output Channel #2	Write	1	0
PWM1	Pulse Width Modulation Channel #1	Write	100.000	0.000
Var1 … 6	Intermediate Variables 1 to 6	Read & Write	Any	Any

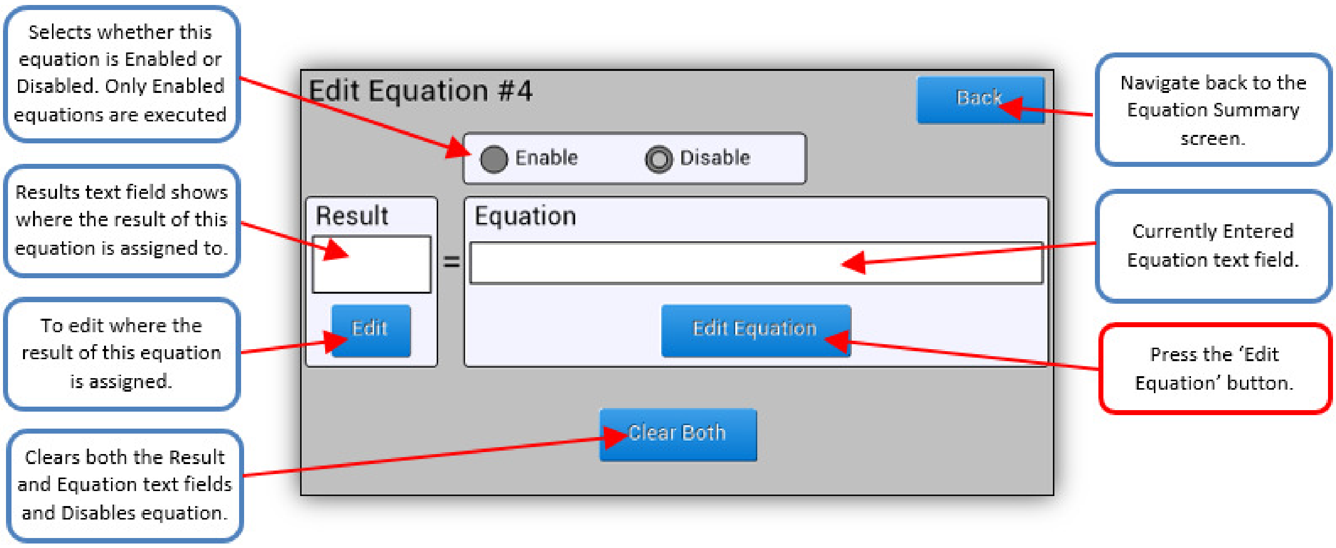
6.1. Equation Setup Example 1

At this point the output of PID Controller #1 is not assigned to any Analogue Output Channels or Intermediate Variables or to PID Controller #2. The following steps will demonstrate how to setup Equation #4 to assigned PID Controller #1's Output to Analogue Output Channel #1.

Notice the red 'Disabled' text in the Equation #4 text box. This means that the AP-100 device will ignore what is or is not in the equation box. Press the corresponding 'Edit' button for Equation #4.

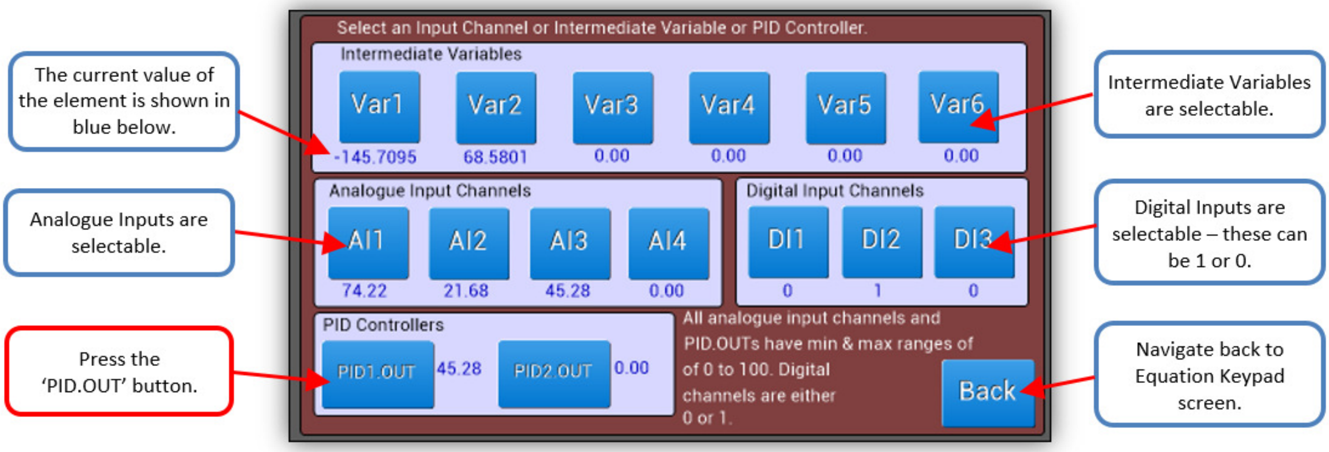


This will show the 'Edit Equation #4' screen which allows you to make changes to this equation, shown below. As can be seen, both the 'Result' and 'Equation' fields are empty and this equation is currently Disabled. To enter an equation, press the 'Edit Equation' button, as shown below.

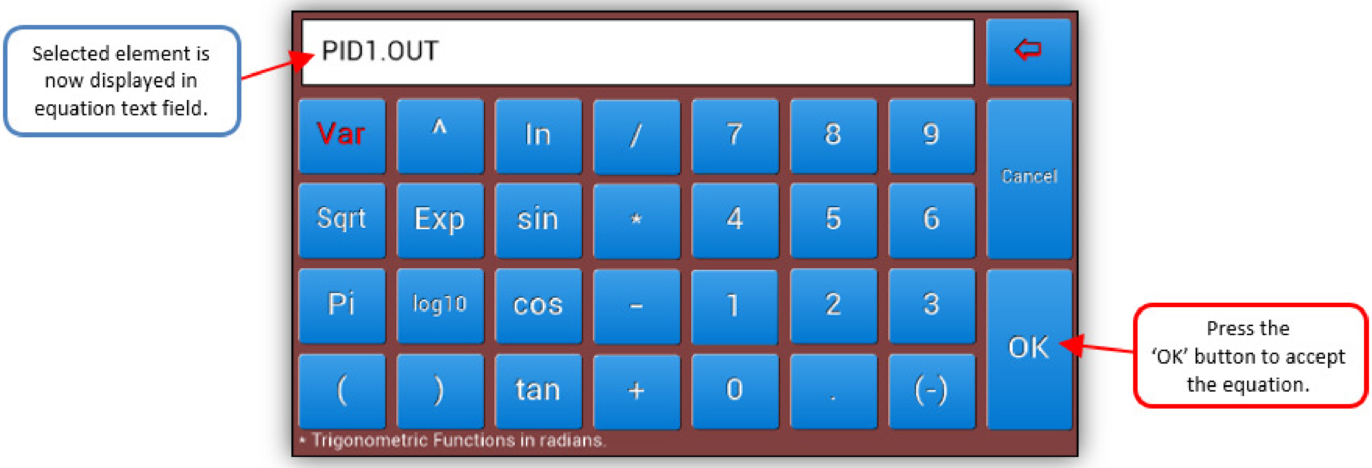


This shall load the 'Equation Keypad' screen as shown below where any equation can be entered. For this example, we wish to make the PID Controller #1's Output element assigned to the Analogue Output Channel #1 element. To select PID Controller #1 Output, press the 'Var' button to show device Inputs, Outputs, PID Controller elements and Intermediate Variables.

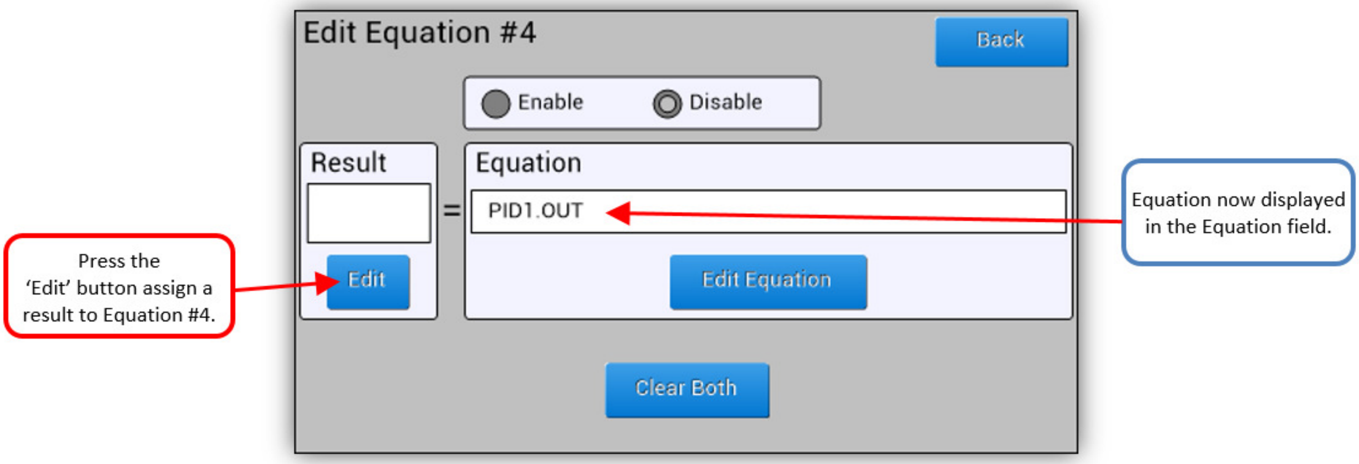
The Variables List screen is shown below, which lists all of the elements that can be Read from and used within the equation text field. It should be noted that the current value of an element is shown in blue. Elements that are not being used will show the value of 0.00. Press the 'PID.OUT' button to select the PID Controller #1 output.



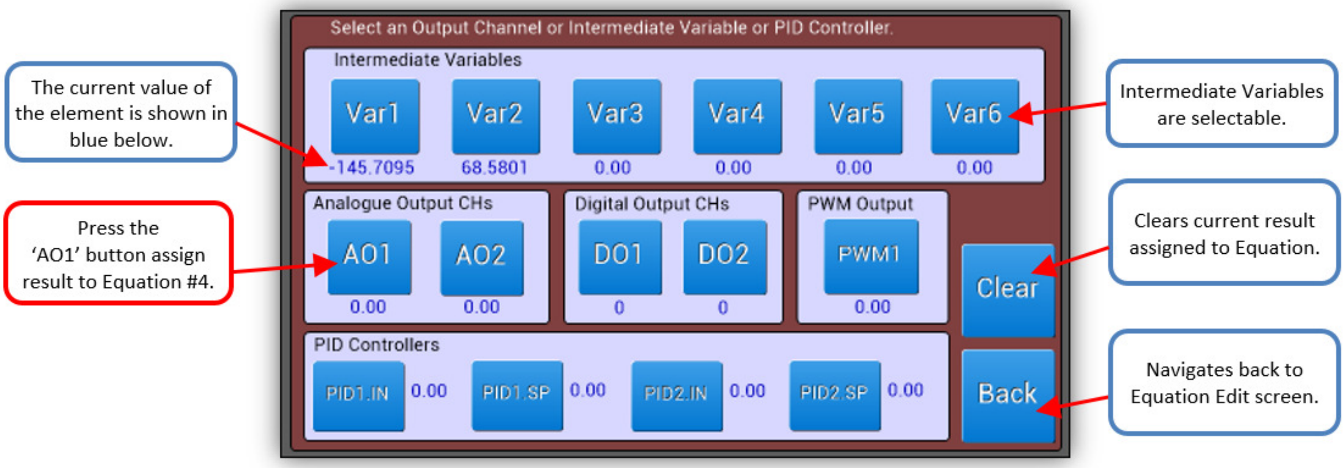
Once an element has been selected the AP-100 device will go back to the 'Equation Keypad' screen and the selected element is now inserted into the equations text field. In the next example we shall use 'PID1.OUT' in an equation but for now press the 'OK' button to return to the 'Edit Equation #4' screen.



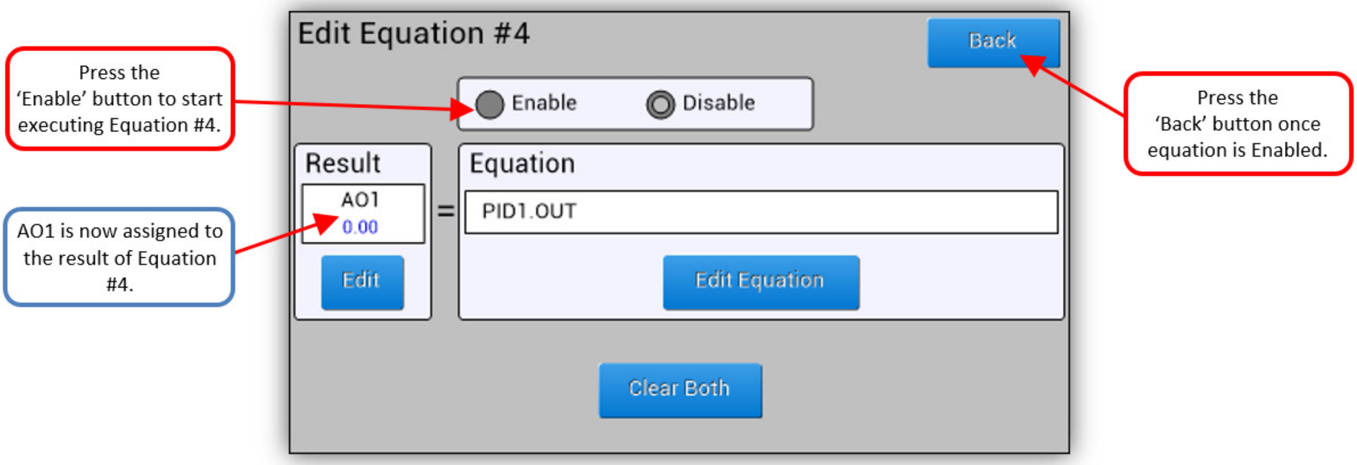
The Equation #4 has been updated with the 'PID1.OUT' element shown in the equation text field. Now we need to assign the result of Equation #4 to the Analogue Output Channel #1. Press the 'Edit' button in the result field.



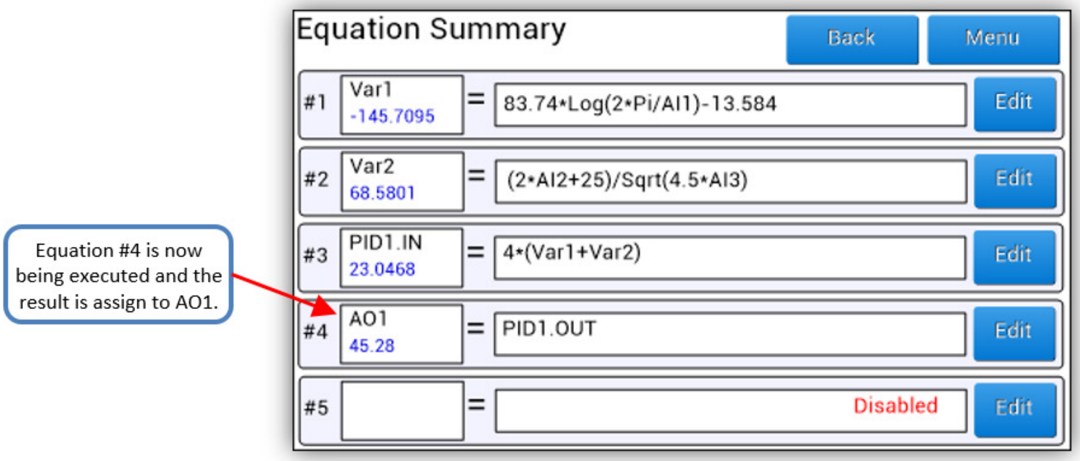
The 'Results Variable List' screen is now displayed showing the available elements and their current values that can be used in the results field of Equation #4. Press the 'AO1' button to assign the PID Controller #1 Output to Analogue Output Channel #1.



As shown below, Equation #4 now has an equation and result element assigned to it, but the blue value in the results field is still showing '0.00' as this equation has not yet been enabled. To enable Equation #4 press the 'Enable' radio button, then press 'Back' to navigate back to the 'Equation Summary' Screen.

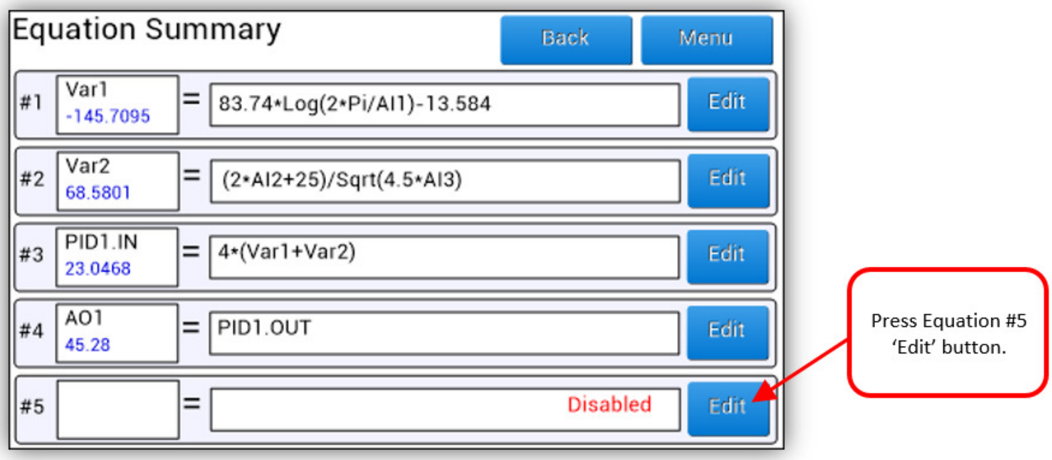


As shown below, Equation #4 now has the element 'PID1.OUT' and its resulting value is now assigned to analogue output 'AO1'. As Equation #4 is now being executed the red 'Disabled' text has disappeared and the value of the result of Equation #4 now appear in blue in the result field.

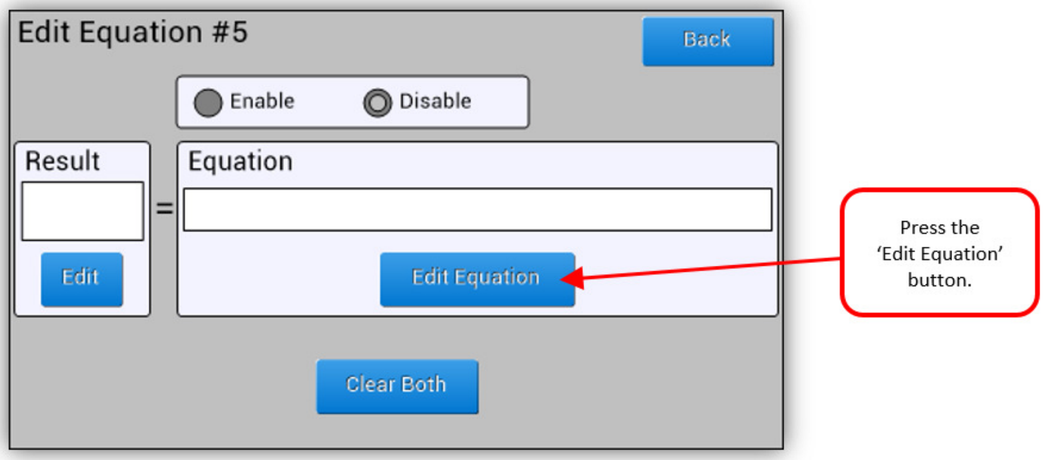


6.2. Equation Setup Example 2

In this next example we shall setup Equation #5 to assign the output of PID Controller #1 to the analogue output channel #2 'AO2' with the following equation: **"AO2 = 15 + (PID1.OUT / 4)".** To do this click on Equation #5's 'Edit' button as shown below.

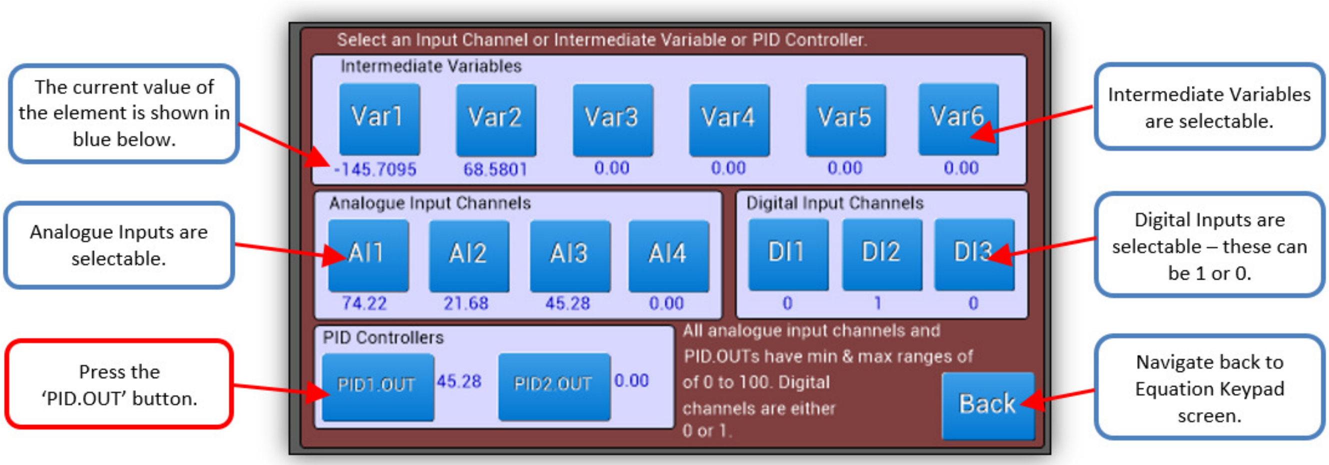


Below shows the 'Edit Equation #5' screen. As before in example 1 press the 'Edit Equation' button.

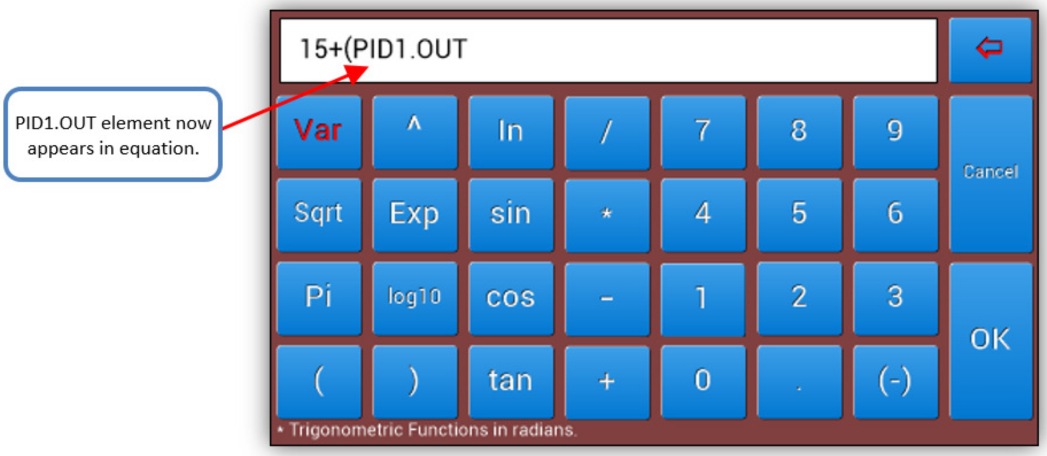


Using the Keypad screen interface, enter in **"15 + ("** as the first part of the **"AO2 = 15 + (PID1.OUT / 4)"** equation. Then press the 'Var' button to bring up the Variables List screen.

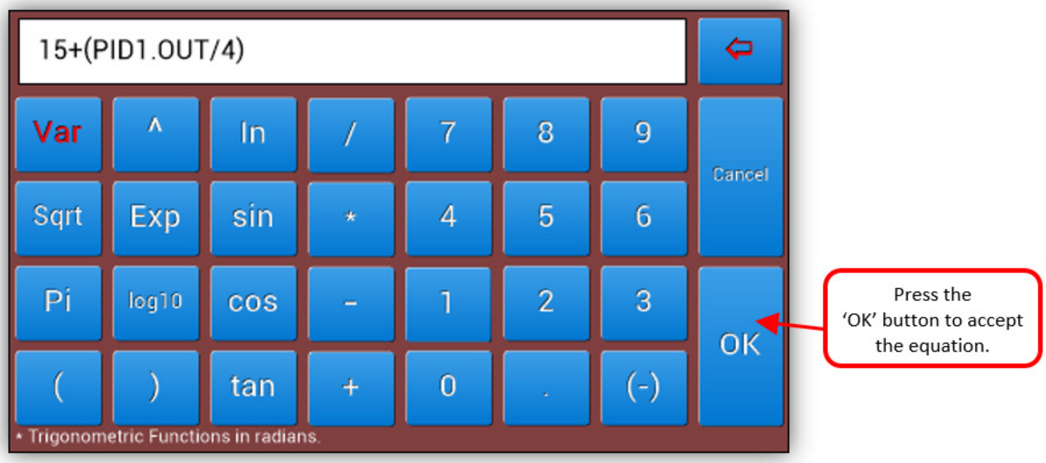
As before in example 1, press the 'PID1.OUT' button to select the PID Controller #1 output signal, as shown below.



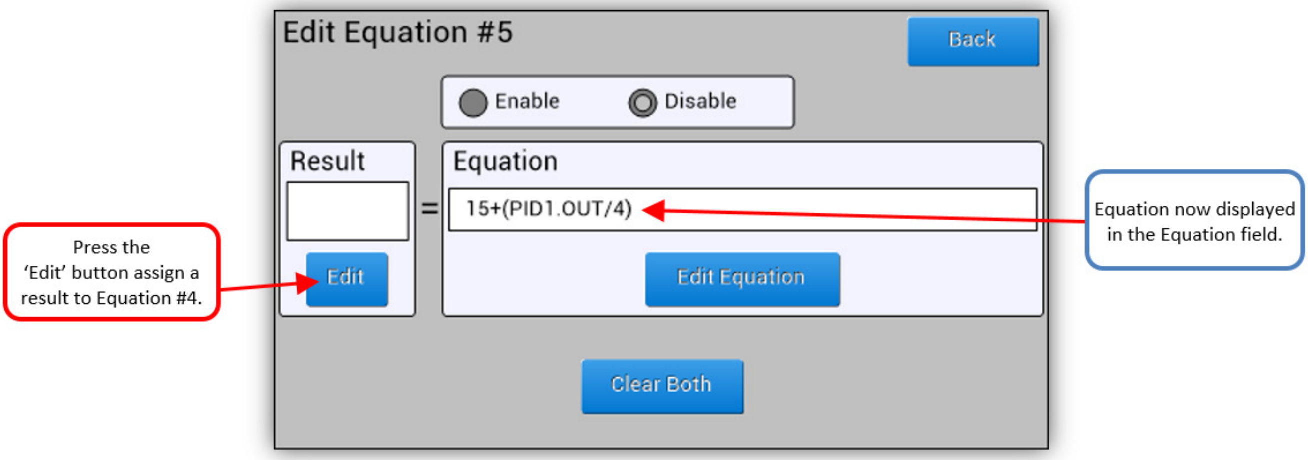
As shown below, the PID Controller #1 output signal element now appears in the equation text field.



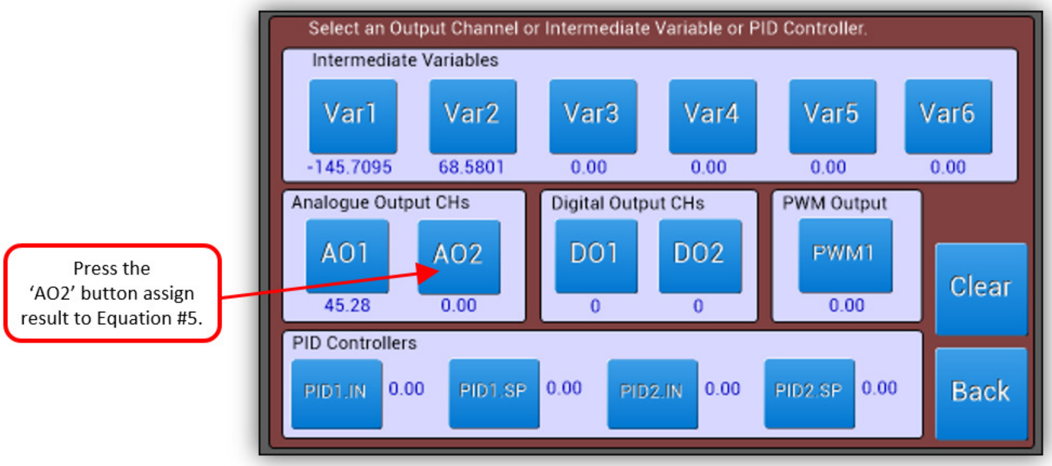
Enter the rest of the **"15 + (PID1.OUT / 4)"** equation and then press the 'OK' button to accept the equation.



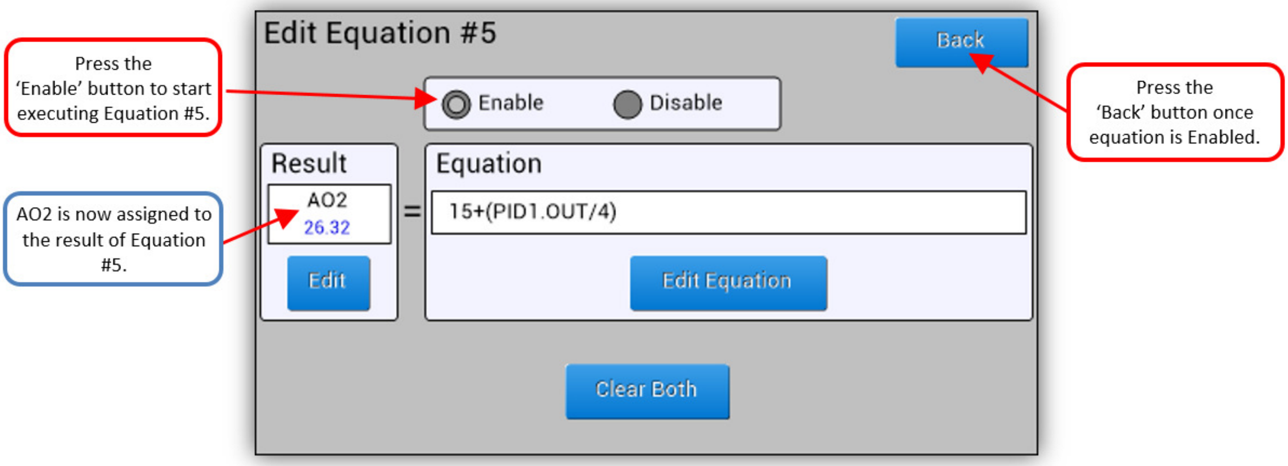
The Equation #5 has been updated with the **"15 + (PID1.OUT / 4)"** equation shown in the equation text field below. Now we need to assign the result of Equation #5 to the Analogue Output Channel #2. Press the 'Edit' button in the result field.



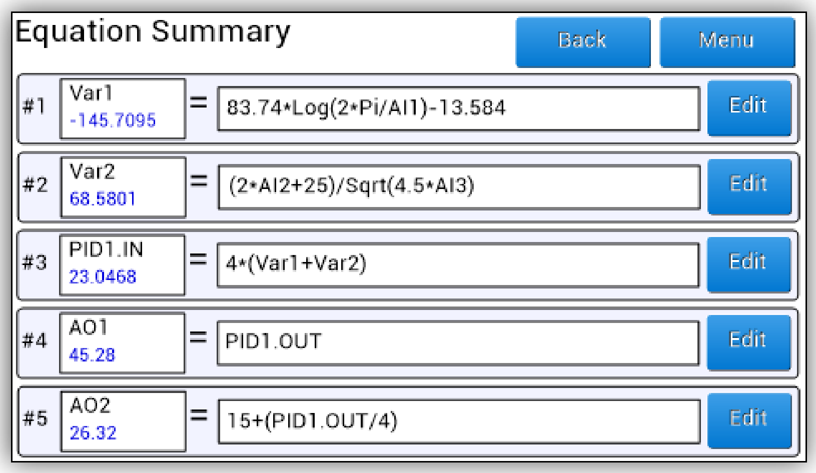
As shown below, press the 'AO2' button the select the Analogue Output Channel #2 and assign it as the result of Equation #5.



Once returns to the 'Edit Equation #5' screen, press the 'Enable' radio button to start executing Equation #5, then press the 'Back' button to go back to the 'Equation Summary' screen.



As shown below, the 'Equation Summary' screen is now displaying Equation #5.



6.3. Equations Further Details

The following should be noted when using mathematical equations:

- Equations follow the BOMDAS convention of "Brackets Of Multiplication Division Addition Subtraction".
- If an analogue value is assigned to a digital output signal, any positive number shall be considered as a logical '1' and any negative or zero value shall be considered as logical '0'.
- All analogue numbers are based on IEEE 754 for 32-bit Floating Point numbers.
- If the result of an equation equal +/- infinity, for example Var1 = 1 ÷ 0, Var1 will equal the max number allowable of +/- 3.4 x 10^{38} according to IEEE 754 for 32-bit Floating Point numbers.
- Analogue Inputs and Outputs can only have a maximum value of 100.0000 or a minimum value of 0.0000. If a value is assigned to an Analogue Output that greater or less than the maximum and minimum, the Analogue Output shall be take the value of its respective maximum or minimum value (an error shall not occur).
- Intermediate Variables (Var1, Var2, Var3, Var4, Var5 & Var6) can be any value supported by 32-bit Floating Point numbers, according to IEEE 754.

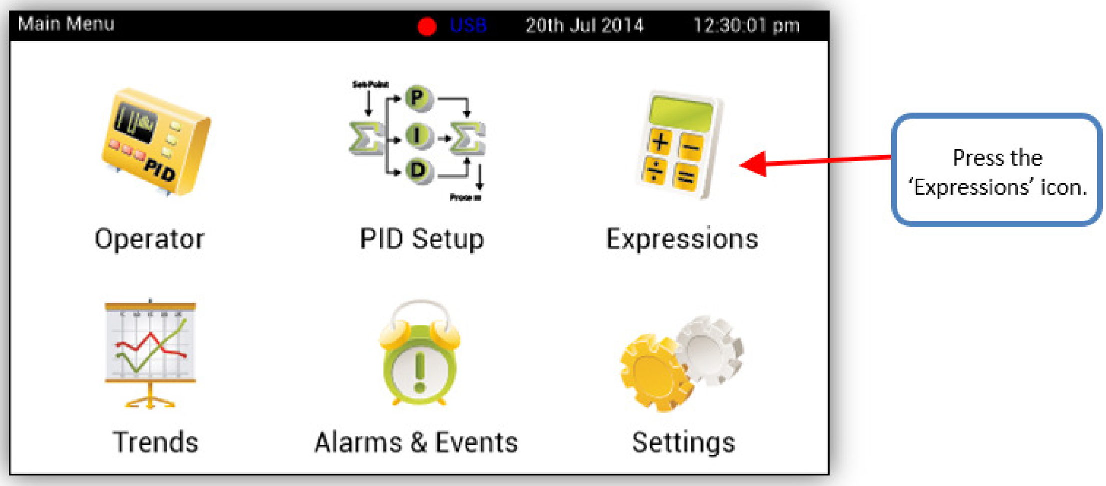
Warning

- Before making setting changes to an online system first consider how this change effects associated outputs.
- It may be necessary to shutdown plant or equipment before making this change.

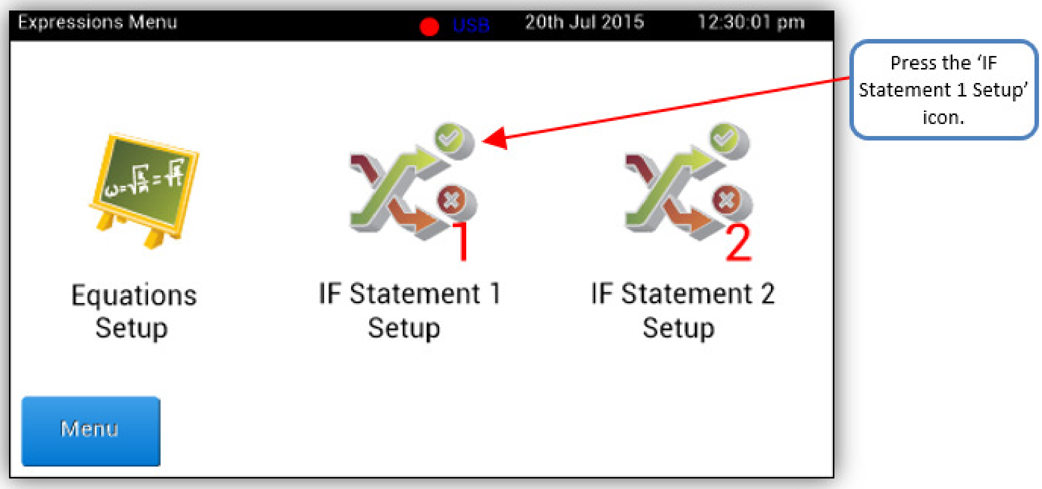
7. IF STATEMENTS SETUP

'IF Statements' are used to evaluate logical expressions and to execute certain equations based on whether the logical expressions are true or false. The AP-100 device supports two different 'IF Statements' which, when enabled, will execute 100 times per second (every 10mS) during each CPU cycle. The AP-100 device's Execution Cycle includes the following: scans all input channels, execute all Equations and IF Statements, then execute both PID Controllers #1 and #2, then lastly update all analogue and digital outputs channels.

To navigate to the 'IF Statements' setup screens, press the 'Expressions' icon from the Main Menu screen as shown below.



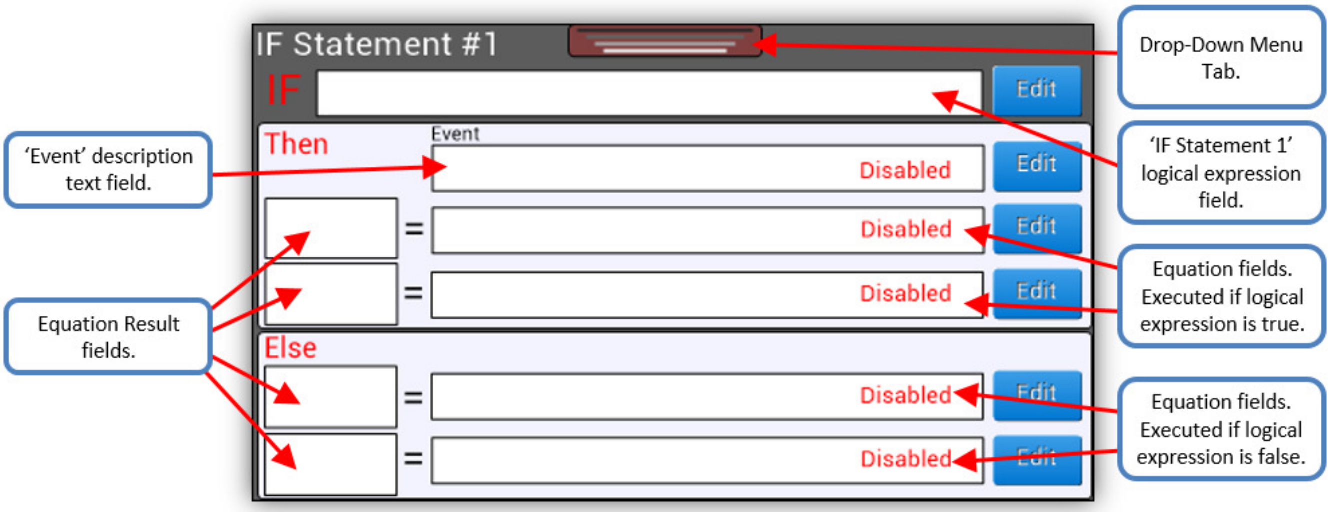
From the 'Expressions Menu' shown below the setup page icons for 'IF Statements' 1 and 2 can be seen. Both of these 'IF Statements' are identical in their setup and operation, so for the following only 'IF Statement 1' shall be discussed. Press the 'IF Statement 1 Setup' icon as shown below.



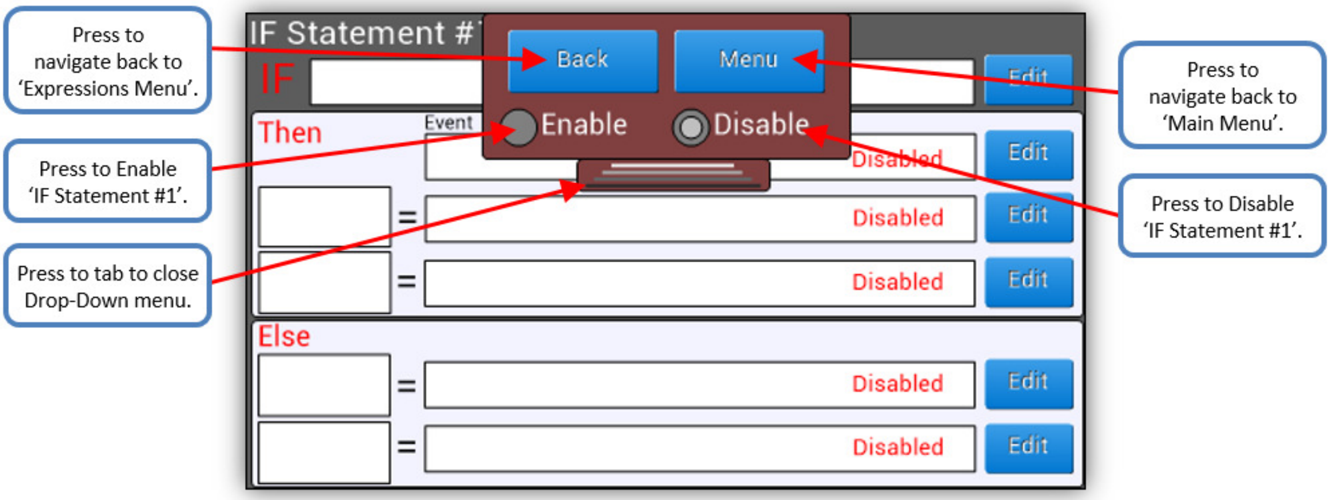
7.1. IF Statement Setup Page

Below shows the setup screen for the 'IF Statement 1'. The IF statements have 3 main sections as follows:

- **Logical Expression** – This is an expression that when processed by the CPU can be either true (logical 1) or false (logical 0).
- **Then Section** – this section can consist of up to two equations and one 'Event'. If this logical expression is evaluated to be true, then the equations are executed every CPU cycle and the 'Event' is logged during the first CPU cycle. (see Section 11 for more information on Alarm & Events)
- **Else Section** – this section can consist of up to two equations. If this logical expression is evaluated to be false, then the equations are executed every CPU cycle.



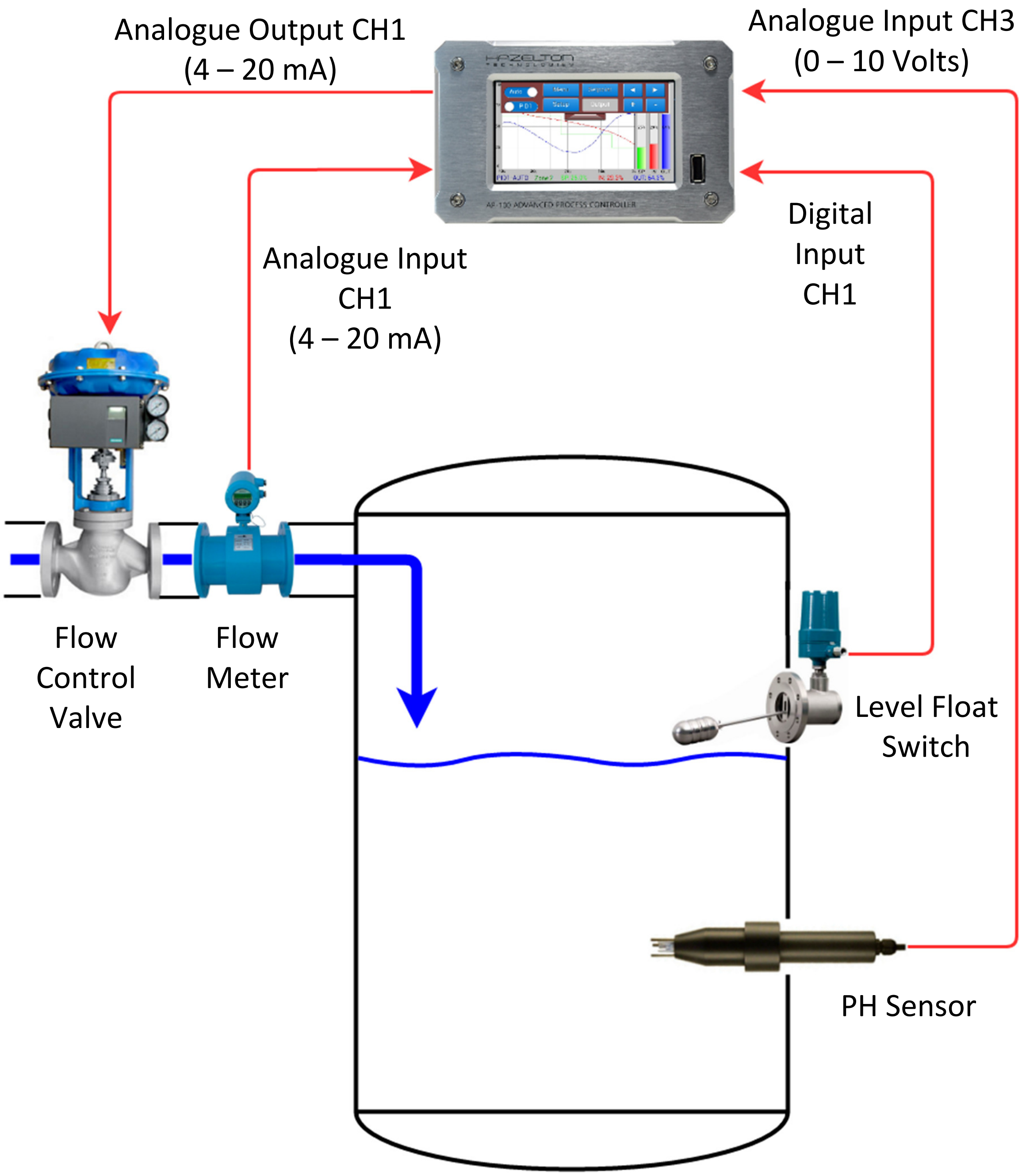
Pressing the tab at the top of the screen displays the Drop-Down menu. This menu displays the 'Enable' and 'Disable' radio buttons. The IF Statement shall not be executed by the CPU unless the 'Enable' radio button is selected. Press the 'Back' button to navigate back to the 'Expressions Menu' or press the 'Menu' button to navigate back to the Main Menu. To close the Drop-Down menu, simply press the tab again.



7.2. IF Statement Example

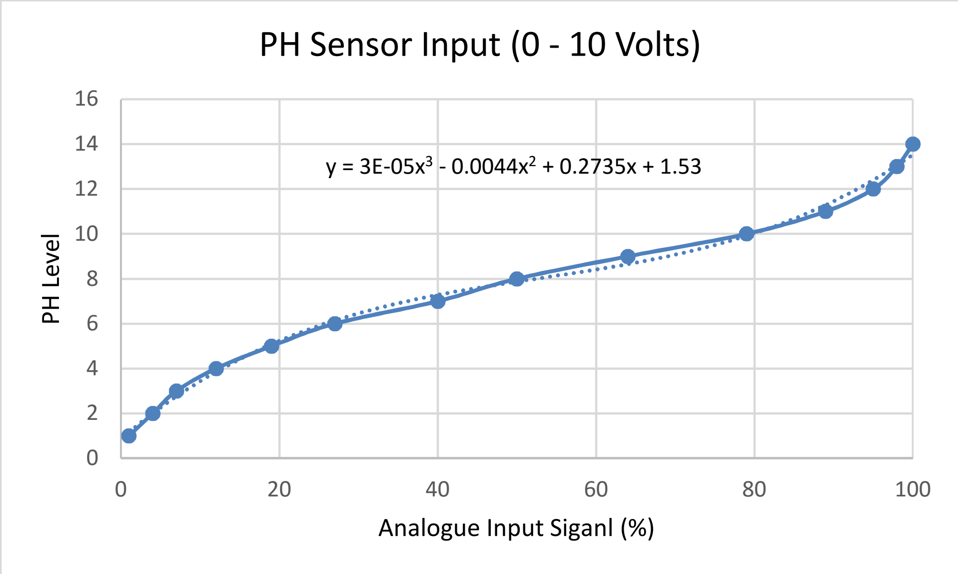
The following example shall demonstrate the setup and function of an IF Statement. The AP-100 device shall be used to control the process as shown below. The below vessel has an inlet pipeline that fills the vessel with a fluid. The AP-100 is being used as a PID controller to control the flow rate of the fluid into the vessel with a control valve and flow meter. The flow meter gives a 4 – 20 mA signal that is connected to Analogue Input Channel #1. The control valve is controlled from a 4 – 20 mA signal from Analogue Output Channel #1 from the AP-100 device. PID Controller #1 is being used as the flow controller.

When the level in the vessel gets to the High Level mark, a float switch activates and sends a digital signal to the AP-100 device via Digital Input CH1. The vessel has PH sensor that outputs a 0 – 10 volt signal and is connected to Analogue Input Channel #3. The PH sensor outputs a non-linear signal which shall be linearized with an equation.



Upon a High Level within the vessel, an IF Statement shall be setup to do the follow:

1. An Event shall be created to log a time stamp of the High Level event.
2. The flow control valve shall be closed to shut off any more flow to the vessel. This shall be done by setting the flow controller's (PID Controller #1) Set-Point to 0%.
3. The PH sensor signal from Analogue Input Channel #3 shall be read and assigned to Intermediate Variable #1 (Var1). The PH sensor does not give a linear output voltage signal verse PH measurement value, as shown in the below graph. Therefore, the below equation shall be used to linearize the input voltage signal into the appropriate PH value.

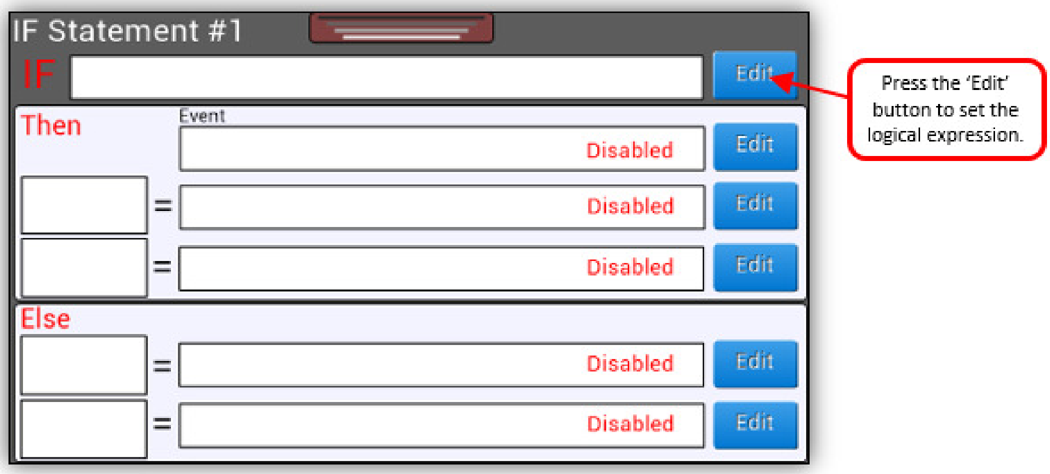


When the High Level float switch signal is not active the following shall occur:

1. The Set-Point of the flow controller (PID Controller #1) shall not be set to 0. Therefore, the user shall be able to change the Set-Point via the 'Operator' screen.
2. The Intermediate Variable #1 (Var1) shall be set to the value of 0.

Note. See relevant section of this manual for more detail on PID Controllers, Input / Output Setup and the Operator screen.

Firstly, the logical expression to be evaluated shall be setup by pressing the relevant 'Edit' button, as shown below.



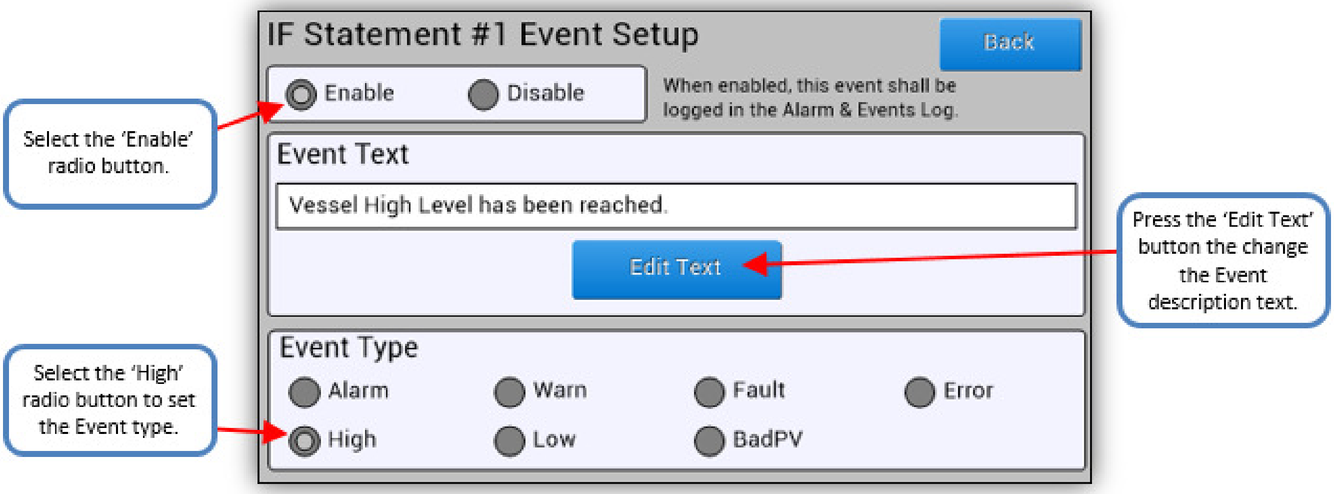
This will display the Expressions edit screen as shown below. In this example, it is the high fluid level within the vessel that is to be evaluated. Therefore, a conditional expression needs to be enter to test whether the Digital Input from the Float Level Switch is active.

The expression “DI1 = 1” shall be evaluated as being true when the Float Level Switch is active and false when it is not active. As indicated below, press the ‘Var’ button to display the Input signals and Variables and select, then select the ‘DI1’ button for the Digital Input Channel #1. Then press the ‘=’ and then ‘1’ buttons. If the screen looks like the below press the ‘OK’ button to accept and return to the IF Statement setup screen.

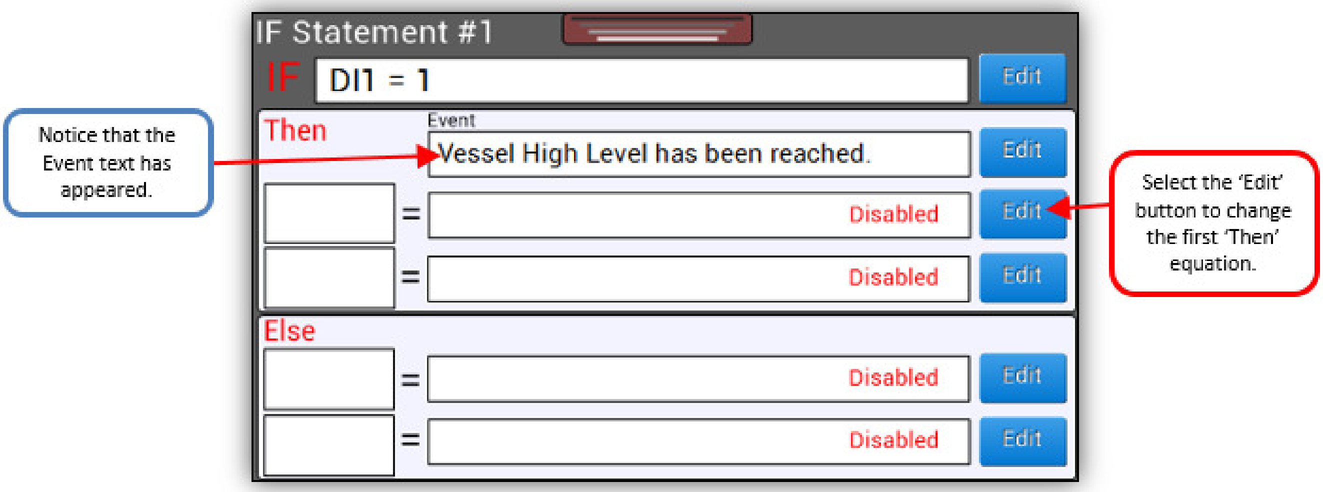
The next step is to setup an Event when the High Level has been reached, to logged the time and date of every time this occurs. As indicated below, press the corresponding ‘Edit’ button for the Event to load the setup screen.

The next step is to setup the ‘Then’ section. This section is executed every CPU cycle when the IF expression is true.

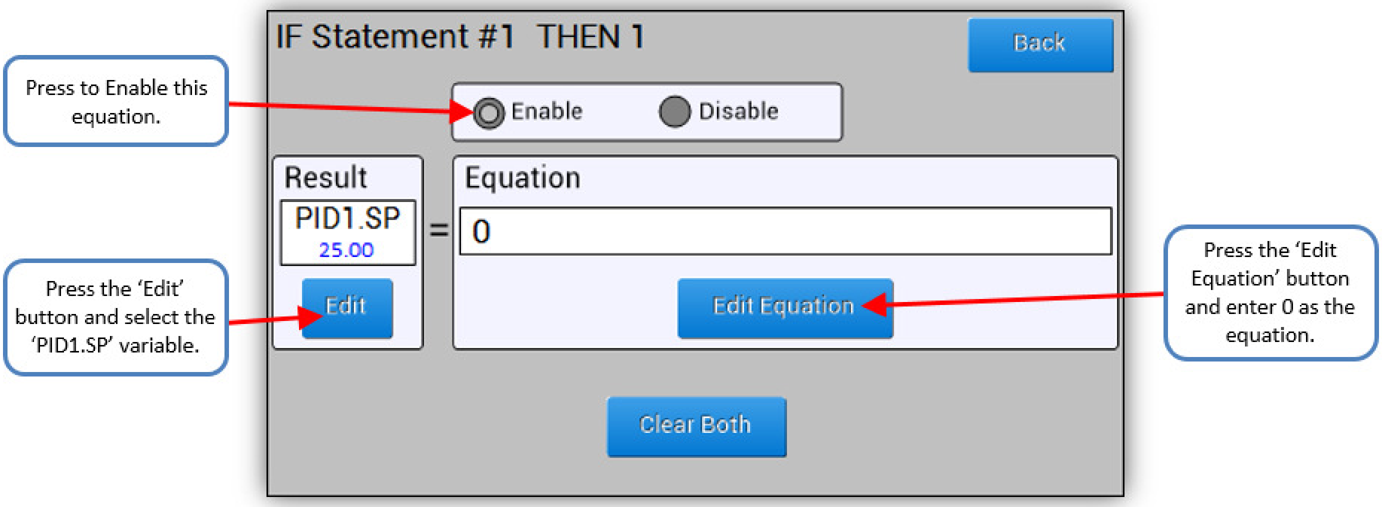
As shown below, press the ‘Edit Text’ button to set the Event description that is approach for the event condition. For this example, the text *“Vessel High Level has been reached”* has been entered. Select the ‘High’ radio button for the Event Type. Then press the ‘Enable’ radio button and then the ‘Back’ button to return to the IF Statement setup screen.



The next step is to setup the equations for the 'Then' section. When the IF statement is true, the flow control valve shall be closed to shut off any more flow to the vessel. This shall be done by setting the flow controller's (PID Controller #1) Set-Point to 0%. As shown below, press the corresponding 'Edit' button for the first equation field.

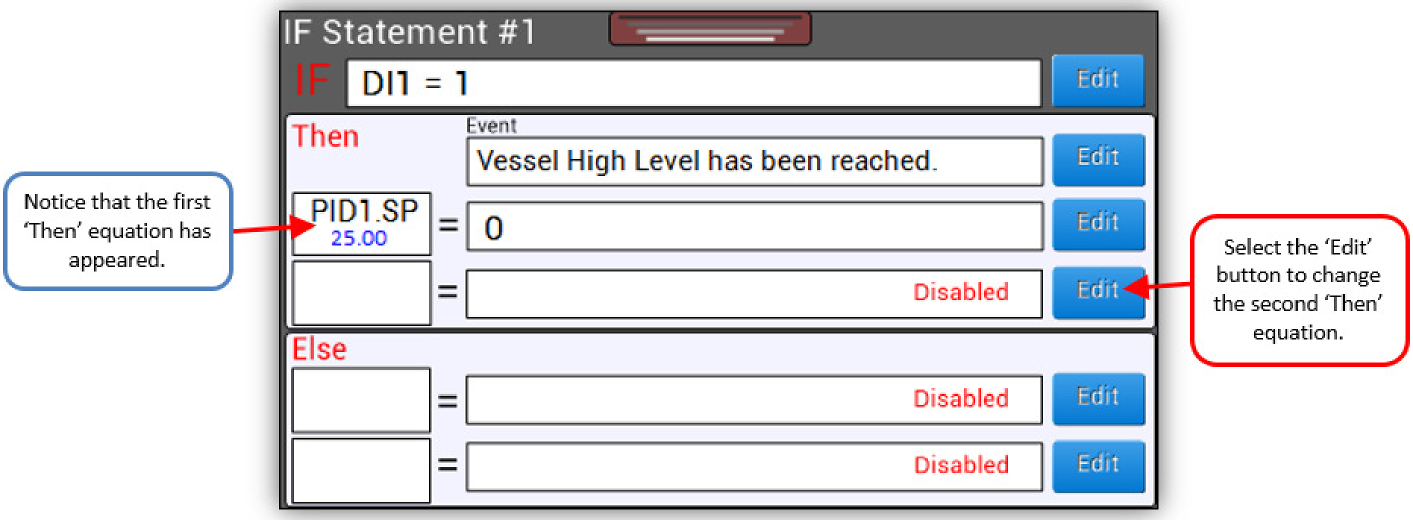


As shown below, enter '0' as the equation and assign this to variable 'PID1.SP'. When this equation is executed it shall assign the value of '0' to the Set-Point of PID Controller #1. Select the 'Enable', then press the 'Back' button.

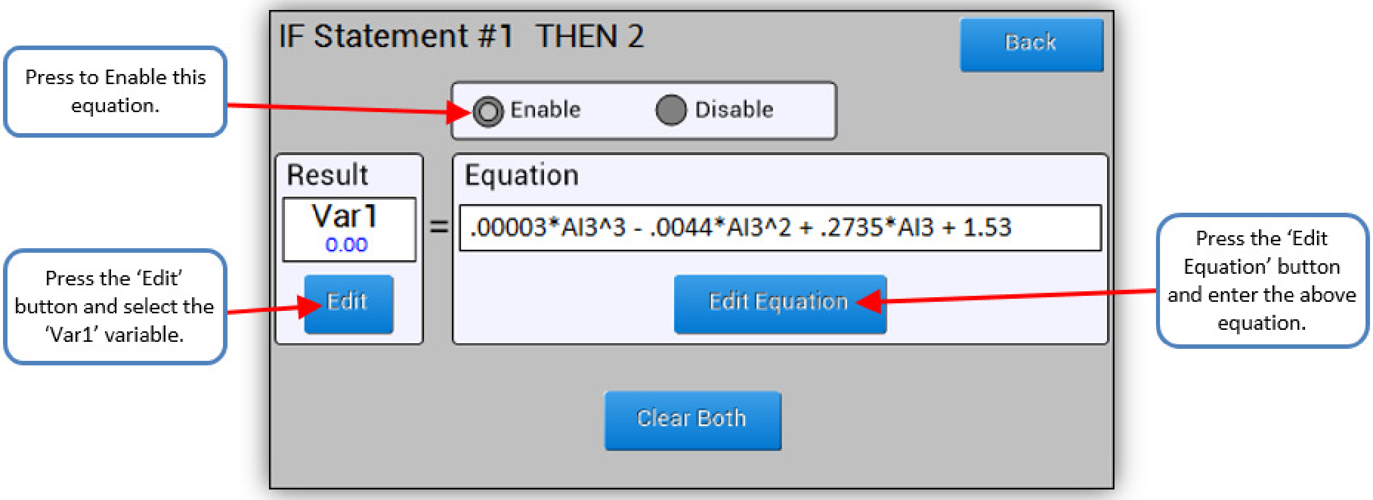


As shown below the first 'Then' equations as appeared and the red 'Disabled' text as disappeared signifying that this equation is now active. Notice the blue text in the Results field showing '25.00'. This is the current value for 'PID1.SP'. It is not '0' as this IF Statement has not yet been enabled.

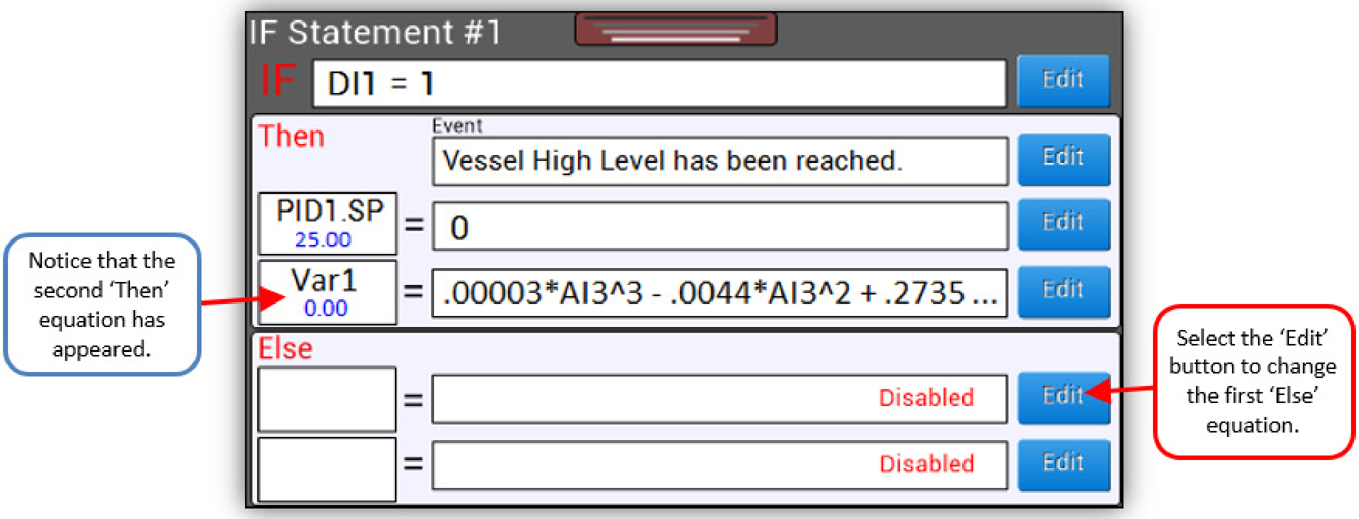
The next step is the set up the second 'Then' equation. The PH sensor signal from Analogue Input Channel #3 shall be read and assigned to Intermediate Variable #1 (Var1). The PH sensor does not give a linear output voltage signal verse PH measurement value, and will need to be linearized with the equation "y = 3E-05x^3 - 0.0044x^2 + 0.2735x + 1.53". However, 'x' shall be substituted with 'AI3' for Analogue Input Channel #3, and the 'y' shall be substituted with 'Var1' for Intermediate Variable #1. Press the corresponding 'Edit' button for the second 'Then' equation.



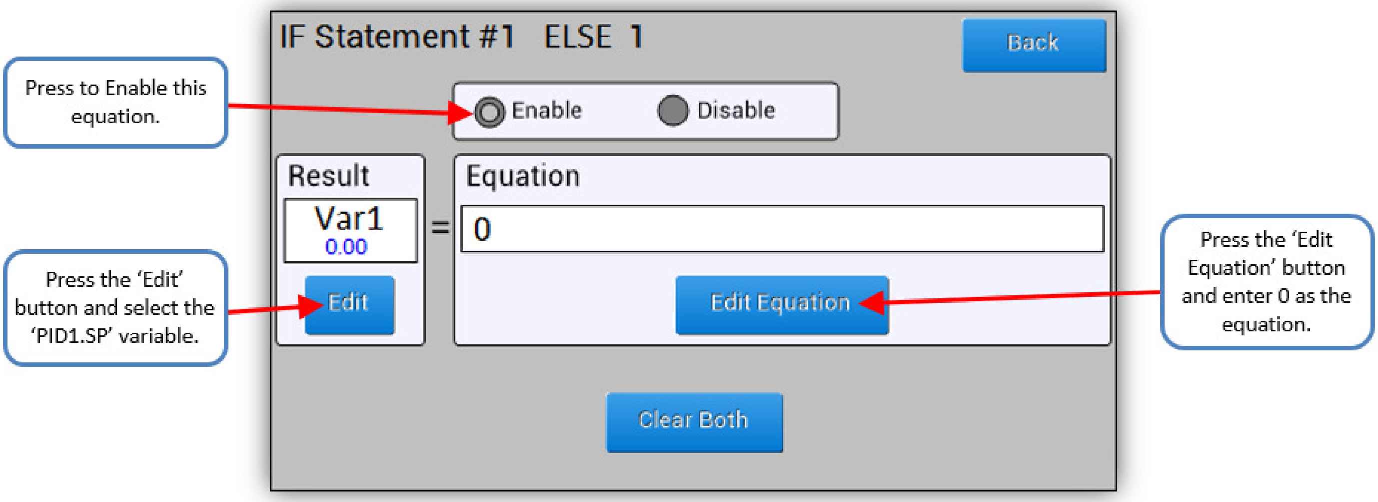
As shown below, enter above equation and assign this to variable 'Var1' (see section 6 for more information on Equations). When this equation is executed it shall assign the linearized PH value to 'Var1'. Press the 'Back' button when finished.



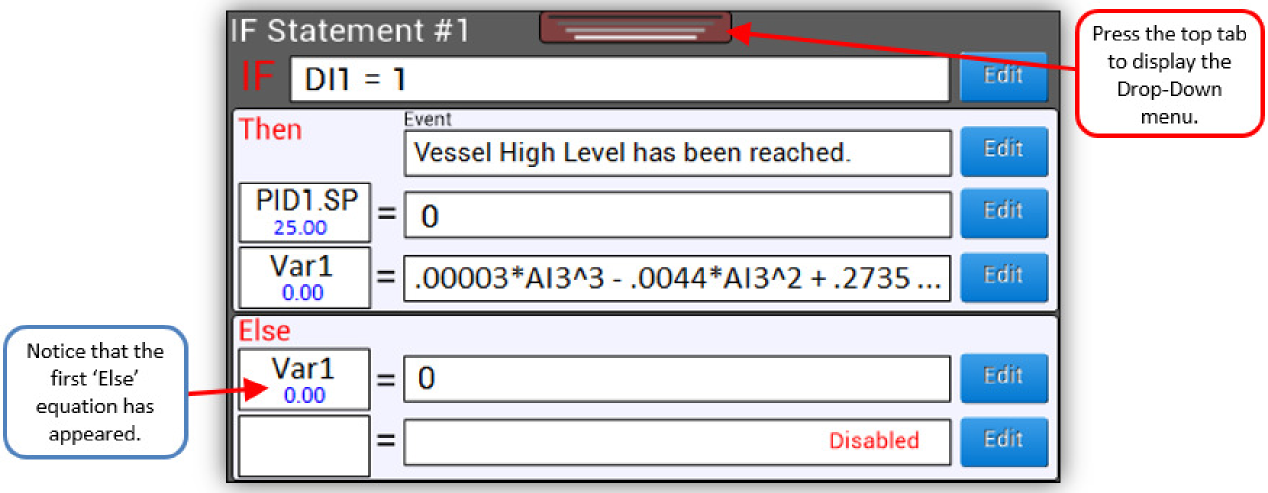
As shown below, the second 'Then' equation has now appeared and the red 'Disabled' text as disappeared signifying that this equation is now active. Then next step is to setup the control actions that need to occur when the Float Level Switch is not active. In this example the Intermediate Variable #1 (Var1) shall be set to the value of 0. To do this pressing the corresponding 'Edit' button of the first equation in the 'Else' section, as shown below.



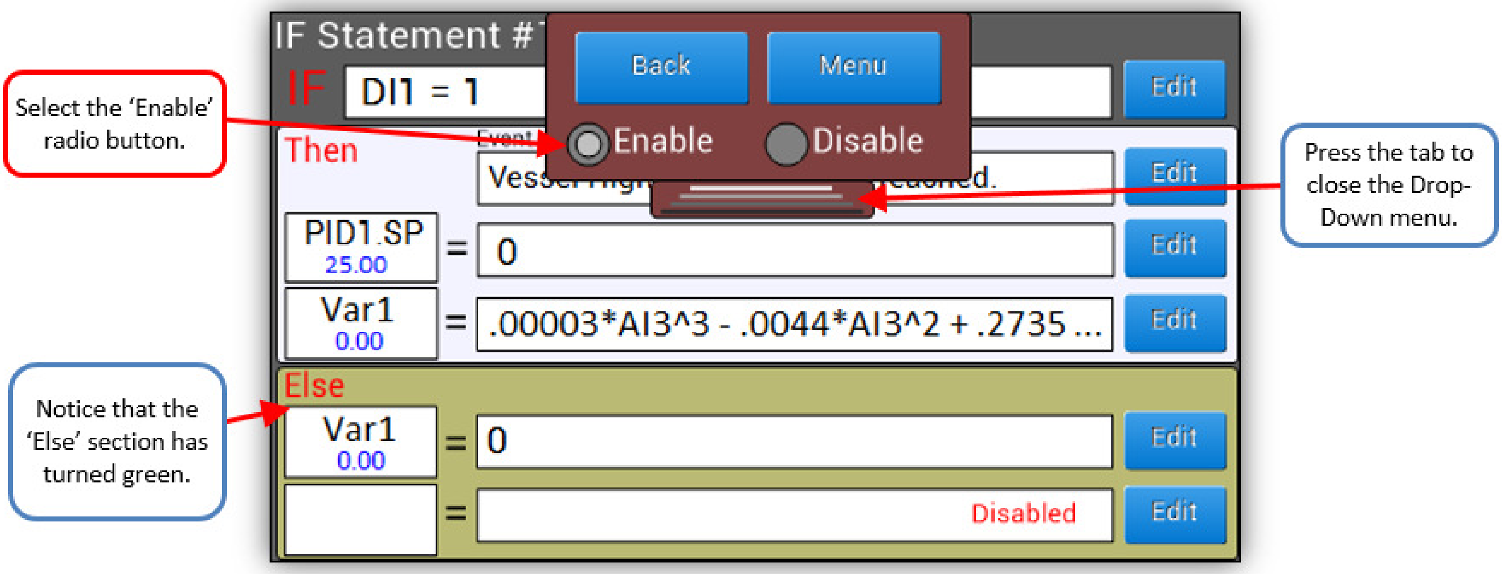
As shown below, enter '0' as the equation and assign this to variable 'Var1'. When this equation is executed it shall assign the value of '0' to Intermediate Variable #1. Select the 'Enable', then press the 'Back' button.



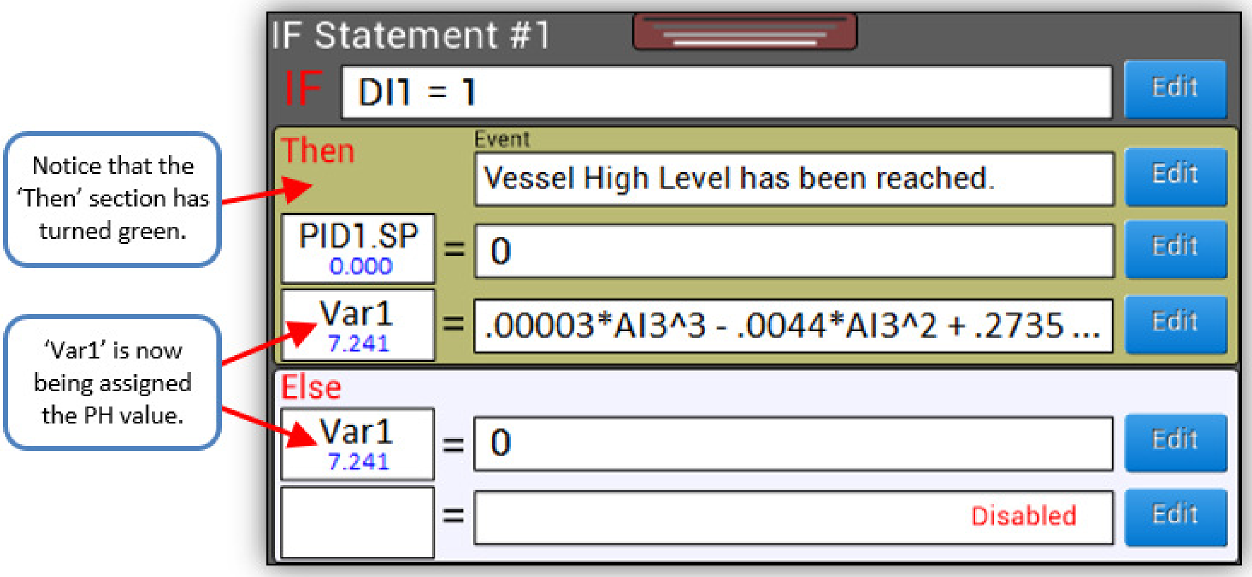
As shown below, the IF Statement #1 is now setup, however it is not yet enabled and being processed by the CPU. To enable, press the tab at the top of the screen to display the Drop-Down menu.



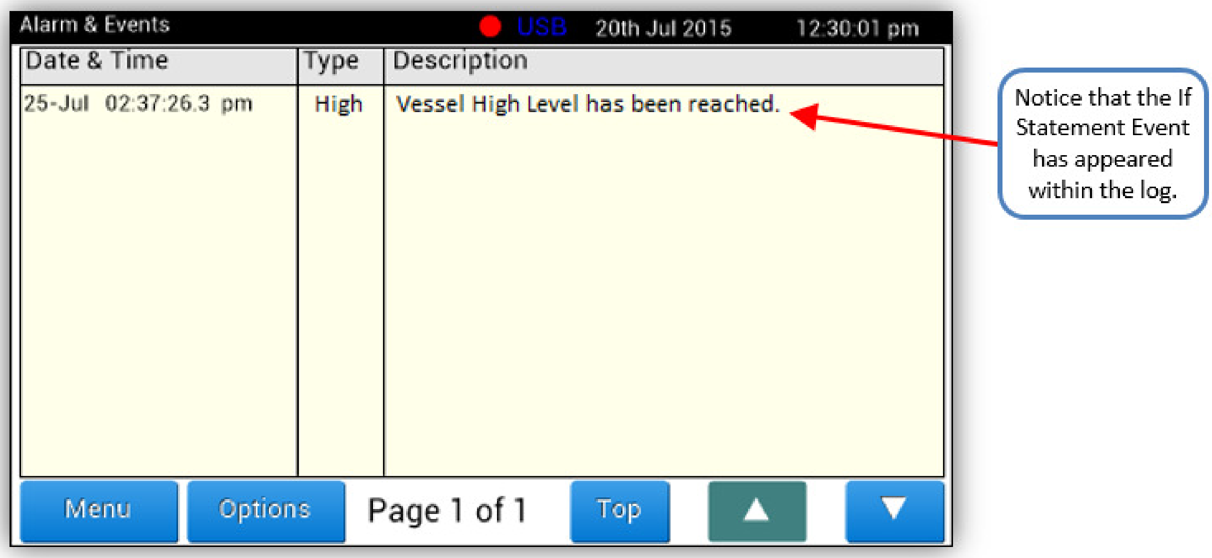
Once the IF Statement #1 has been enabled the CPU shall start evaluating the logical 'IF' expression, and depending on whether the expression is true or false, will determine whether the equations in the 'Then' or 'Else' sections are executed. Notice below that the 'Else' section has turned green. This is because the Float Level Switch (Digital Input CH1 or DI1) is not active and therefore the logical 'IF' expression of 'DI1 = 1' is evaluated to be false. Hence the intermediate variable 'Var1' will be assigned the value of '0'.



Below shows the 'IF Statement #1' when the Float Level Switch (Digital Input CH1 or DI1) is active and therefore the logical 'IF' expression of 'DI1 = 1' is evaluated to be true. Notice that the 'Then' section has now turned green and the equations in this section are now being executed. As stated earlier, the IF Statements and active section (Then or Else) are processed every 10mS (100 Hz). This means that for the below, 'PID1.SP' shall be assigned the value of '0' every 10mS and 'Var1' shall be updated with the latest equation values as 'AI3' is updated every 10 mS also.



The Event within the 'Then' section is only logged once as this section becomes active. To view this event, navigate to the 'Alarms & Events' screen to see the event with date and time stamp appear in the log as shown below.



For more information on Alarm & Events see section 11.

Warning

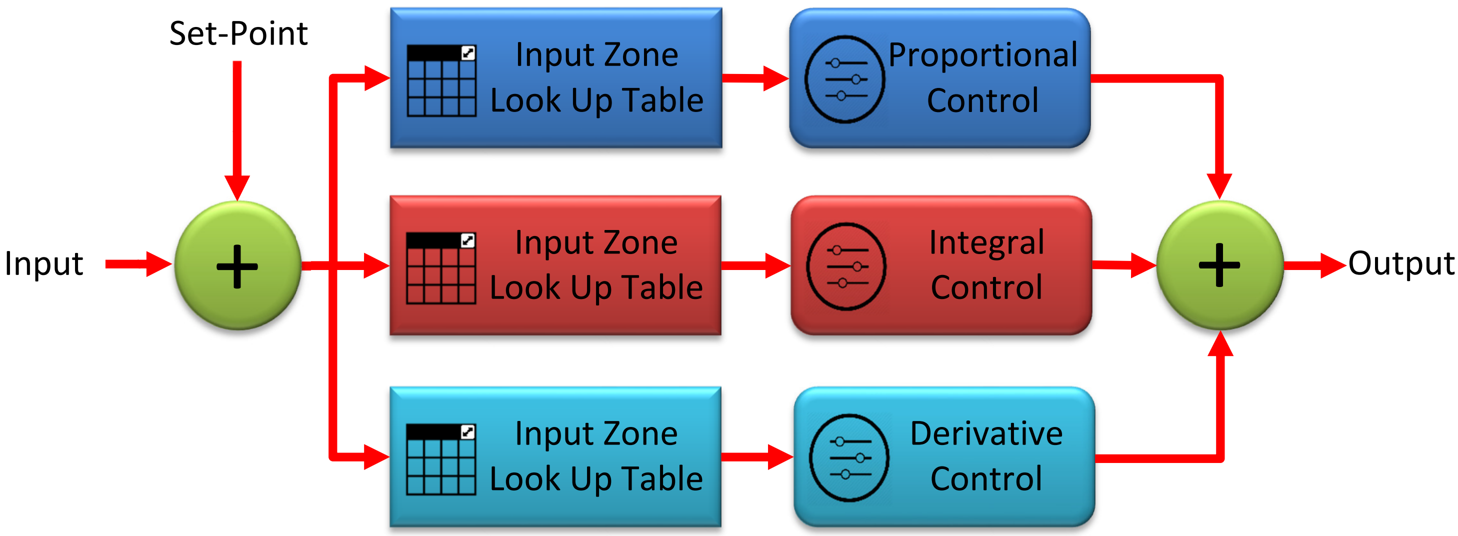
- Before making setting changes to an online system first consider how this change effects associated outputs.
- It may be necessary to shutdown plant or equipment before making this change.

8. PID CONTROLLER'S SETUP

The AP-100 Advanced Process Controller has two Proportional, Integral & Derivate (PID) Controllers that can be configured as two separate PID controllers, or in Feedforward Mode, or in Cascade Mode (Master + Slave). Both PID controllers have very fast execution times and can be user selected to execute up to 50 times per second (50 Hz). The AP-100 device's Execution Cycle includes the following: scans all input channels, execute all Equations and IF Statements, then execute both PID Controllers #1 and #2, then lastly update all analogue and digital outputs channels. This is Execution Cycle is depicted in the below diagram. It should be noted that the full Execution Cycle occurs 100 times per second (100 Hz), but the PID Controller's maximum execution rate is every second cycle.

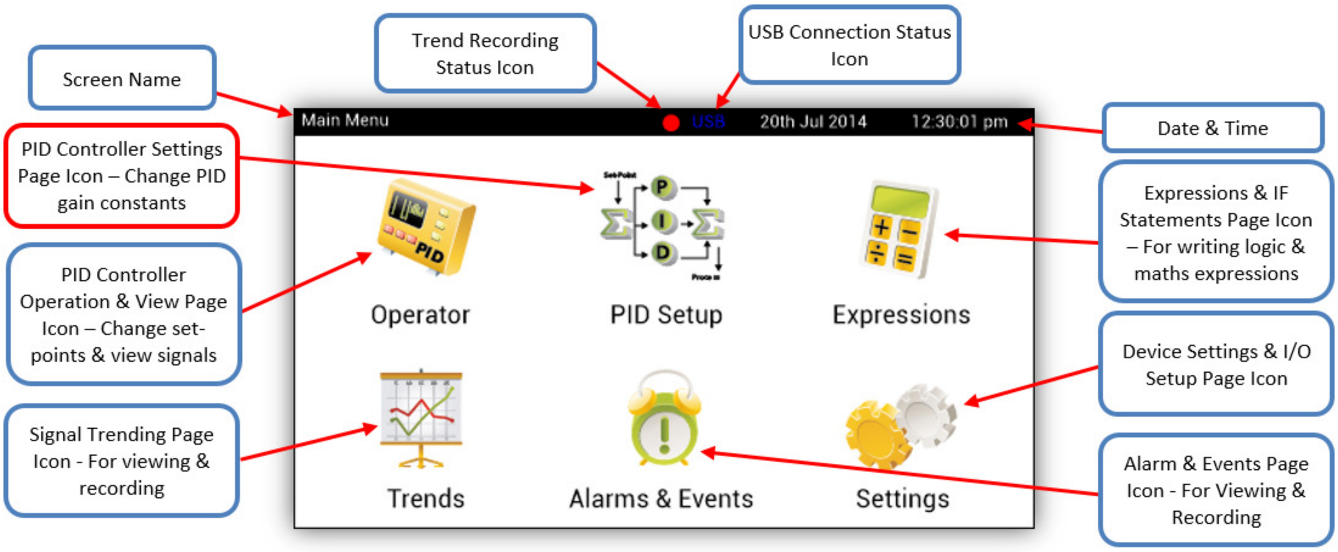
The below diagram outline's the PID Controller element, both PID Controllers are exactly the same. A signal PID controller has the following parts:

- **Set-Point** – This is set either manual via the 'Operator' Screen (Section 9) or configured by an equation (section 6) or configured by an IF statement (section 7).
- **Input** – This is configured equation (section 6) or configured by an IF statement (section 7).
- **Output** – This is configured equation (section 6) or configured by an IF statement (section 7).

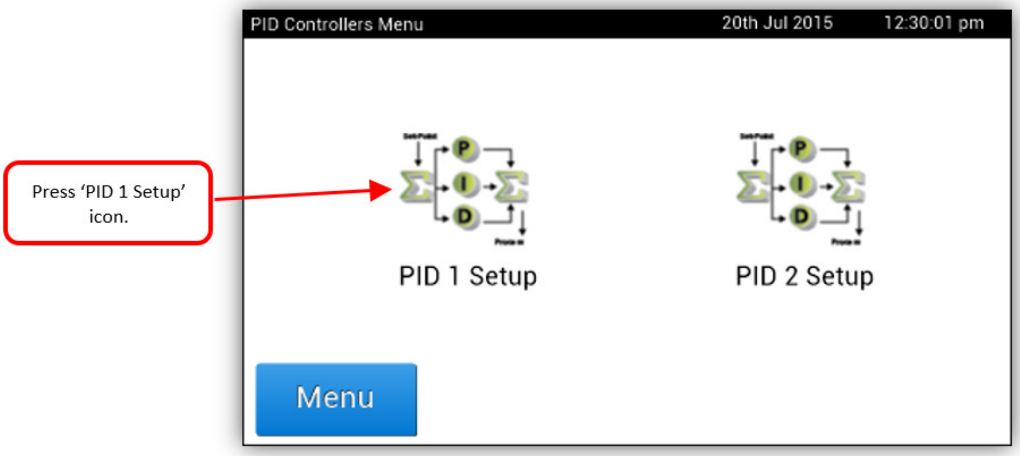


As shown above, each PID gain constants (Proportional, Integral and Derivative) can be configured to have a Look Up table to select specific gain constants vs Input signal value. This is done by dividing the Input signal into a number of zones that is user selectable from 1 to 5. The PID controller shall determine which gain constants to use, depending on which zone the Input signal is in. This is very useful for non-linear process control problems where the PID controller will have the best performance if it can have different gain constants for different Input signal ranges. The Set-Point and Manual/AUTO modes are set using the 'Operator' screen (see Section 9).

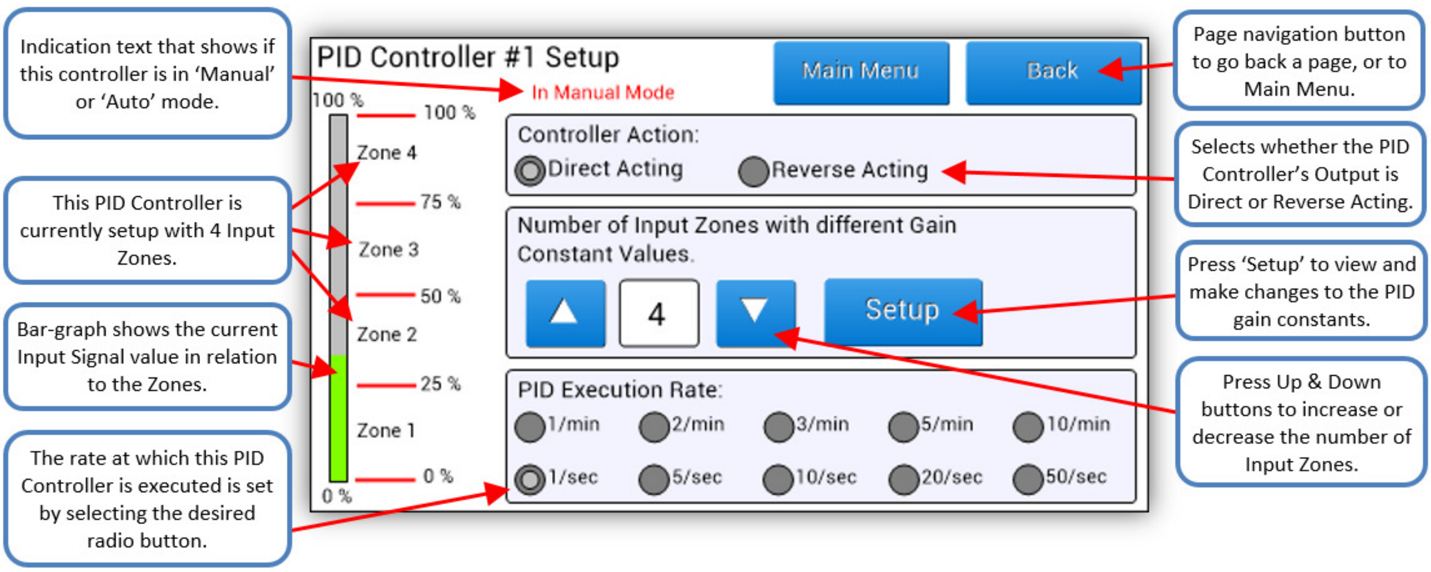
To navigate the PID Controllers Setup screen, select the 'PID Setup' icon from the 'Main Menu' screen, as shown below.



The 'PID Controller Menu' displays the setup icons for both PID Controllers #1 and #2. Both of these controller's setup and function are identical so the following instructions shall display examples for PID Controller #1, but this information can be equally applied to PID Controller #2. Select the 'PID 1 Setup' icon to load the setup screen as shown below.



Below shows the 'PID Controller 1' setup screen.



8.1. Direct or Reverse Acting Controller

As shown above, to set the controller as Direct or Reverse acting, press the corresponding radio button. Whether a controller needs to be direct or reverse acting is determined by the configuration of the process. For example, in the case of a tank level control, it depends on the placement of the control valve. If the valve controls the flow out of the tank, it would have a positive error (level too high) to increase the control output. Therefore, opening the valve and letting more fluid out of the tank; thus, a direct acting controller would be used. If the valve controls the flow into the tank, however, a reverse acting controller would be used, which would respond to a high level by closing the valve and reducing the flow into the vessel.

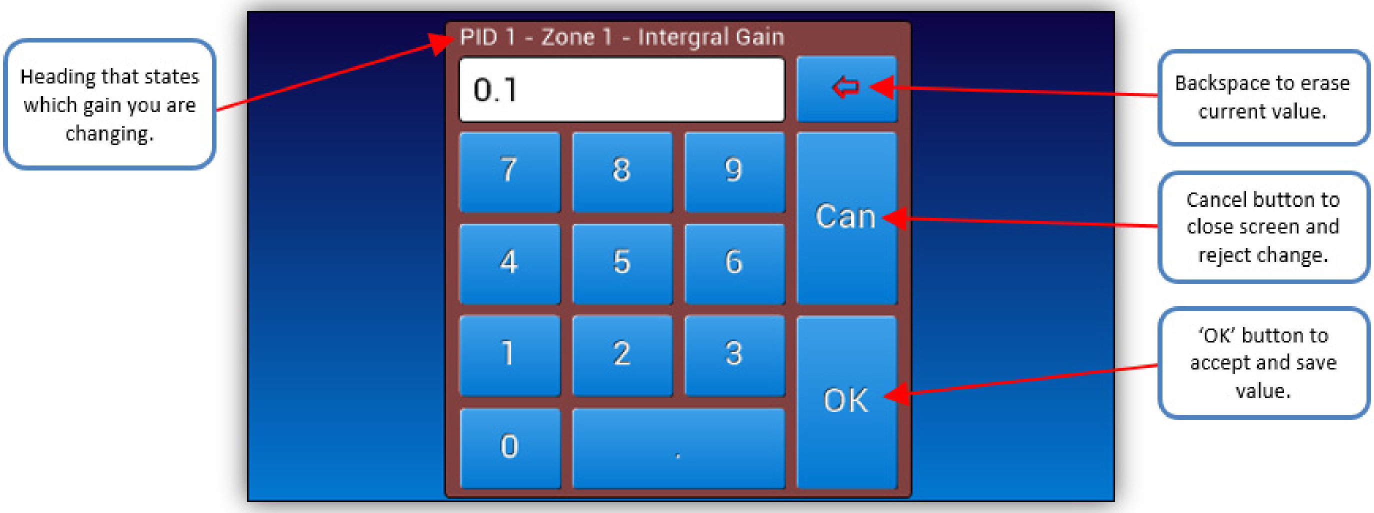
8.2. Controller Execution Rate

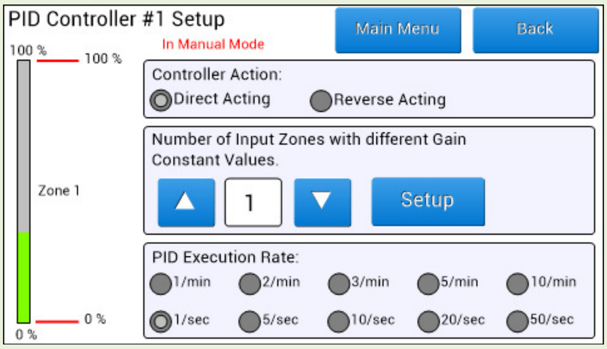
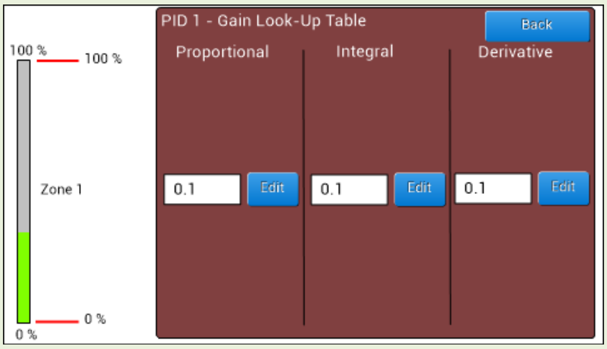
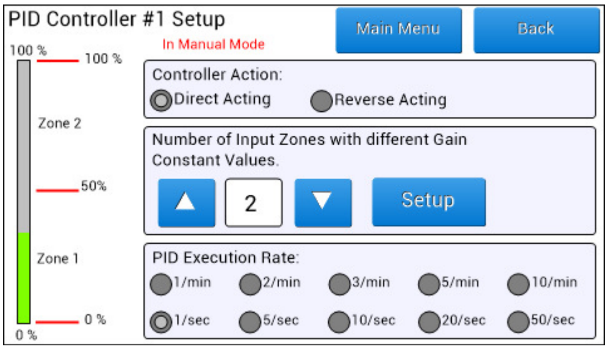
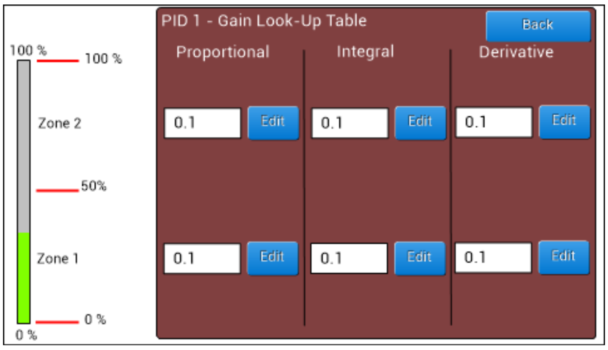
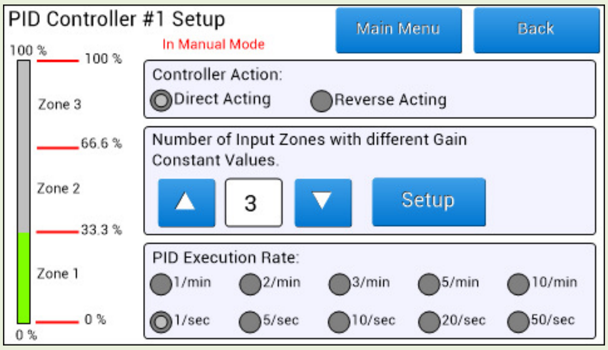
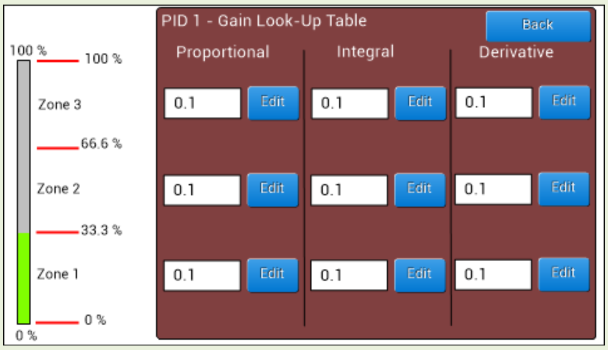
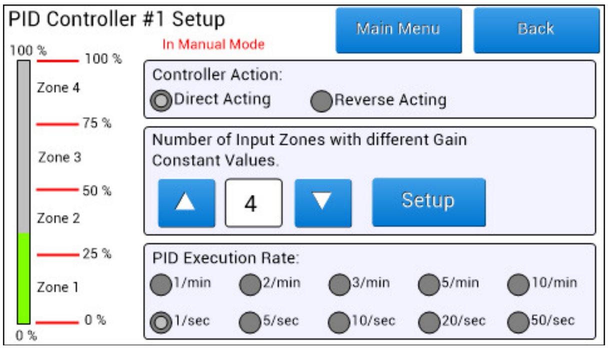
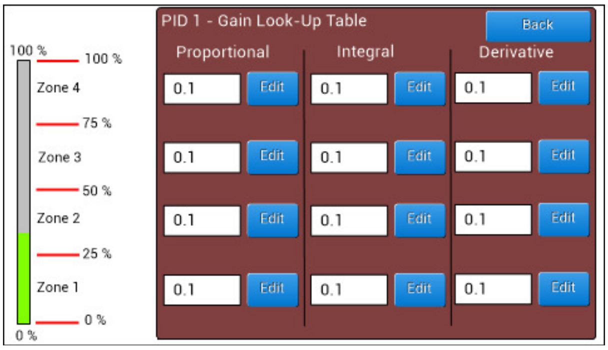
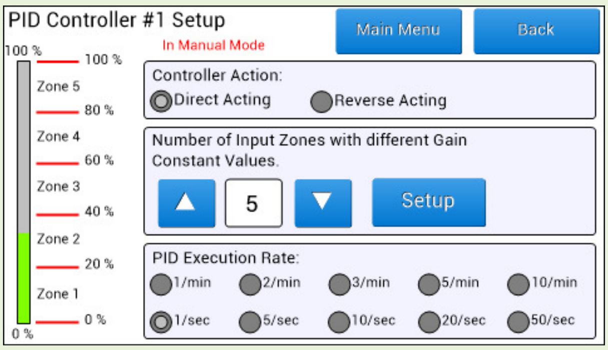
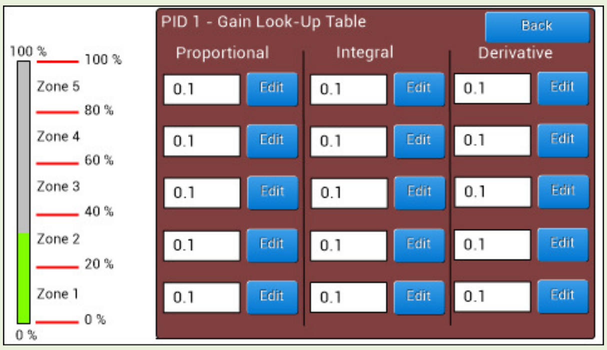
As shown above, to set the controllers execution rate, press the corresponding radio button. For example; if the '3/min' radio button is selected, then the PID controller shall execute three times every minute. If the '10/sec' radio button is selected, then the PID controller shall execute ten times per second (every 100mS).As stated earlier the Input channels are scanned then the Equations and IF Statements are executed, if at this point the controller time to be executed has elapsed (according to these radio button) the PID controller shall execute. Lastly the Output channels are updated.

8.3. Separate Zone Gain Constants

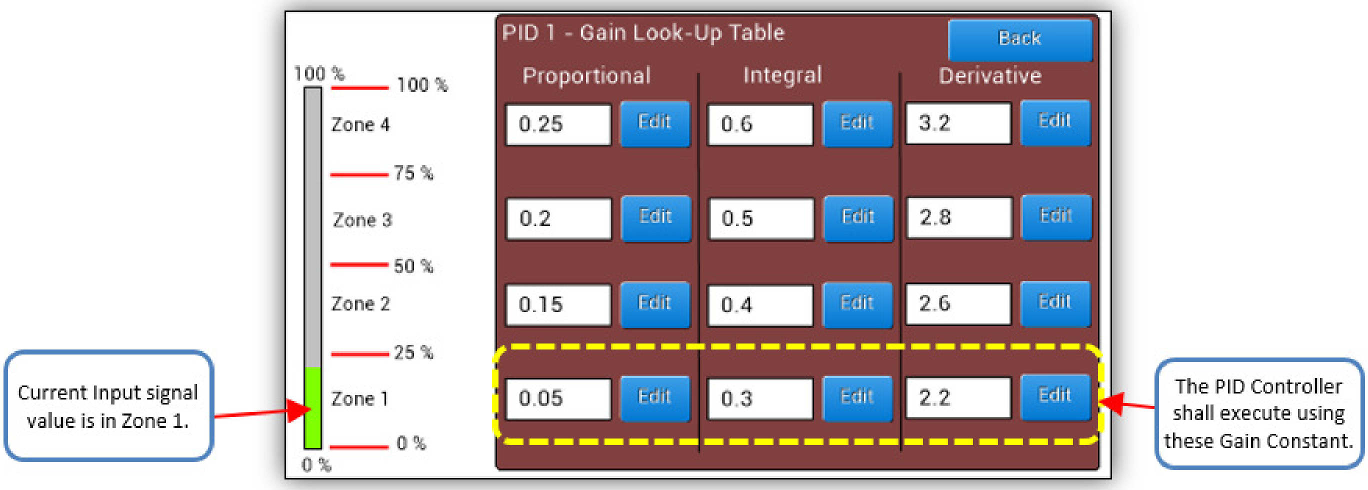
The Input signal range from 0.00% to 100.00% can be divided up into zones. The user can select how many Zones to use from 1 Zone to 5 different Zones using the Up and Down arrow buttons as shown above. For each Zone that is used; there is a separate set of Proportional, Integral and Derivative gain constants that can be set for that Zone. This allows the PID controller to have different performance characteristics through-out a given Input signal range.

The table below shows how the Input signal range is divided up, verse the number of Zones that are chosen with Up and Down arrow buttons. To see the 'Zone Look-Up Table' with the corresponding PID gain constants, press the 'Setup' button as shown above. The left column of screens shows the normal PID setup screen with number of zones increasing down the table rows. In the right column, the 'Zone Look-Up Table' is shown, notice that there are a set of PID gain constants for each zone. To close the 'Zone Look-Up Table' simply press the 'Back' button in the top right-hand corner. By default, all of the PID gain values are 0.1, to change a given value press its corresponding 'Edit' button. This shall display the below keypad that will allow the user to change the value.

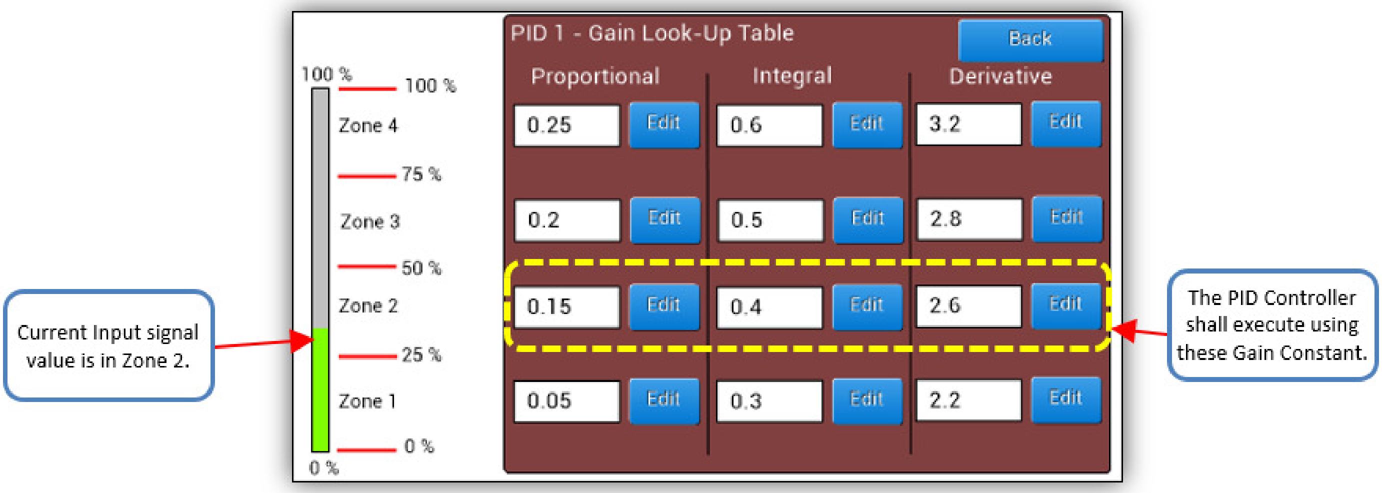


Number of Zones	Setup Screen	Setup Screen with Look-Up Table
1 Zone		
2 Zones		
3 Zones		
4 Zones		
5 Zones		

The following example shall illustrate the function of Zones and different sets of PID gain constants. The PID controller shown below has been configured with 4 zones. Each zone has a different set of PID gain constants that have been found to perform the best for this application. Notice that the Input signal as depicted on the bar-graph on the left below 25% and above 0%. This is the range of Zone 1 and therefore the highlighted PID gain constants shall be used when this PID controller is executed.



As the process-under-control conditions change, so shall the Input signal. Below the Input signal has now increased to above 25% but below 50%, which is the range of Zone 2. Now this PID controller is executing using Zone 2's PID gain constants as highlighted below.



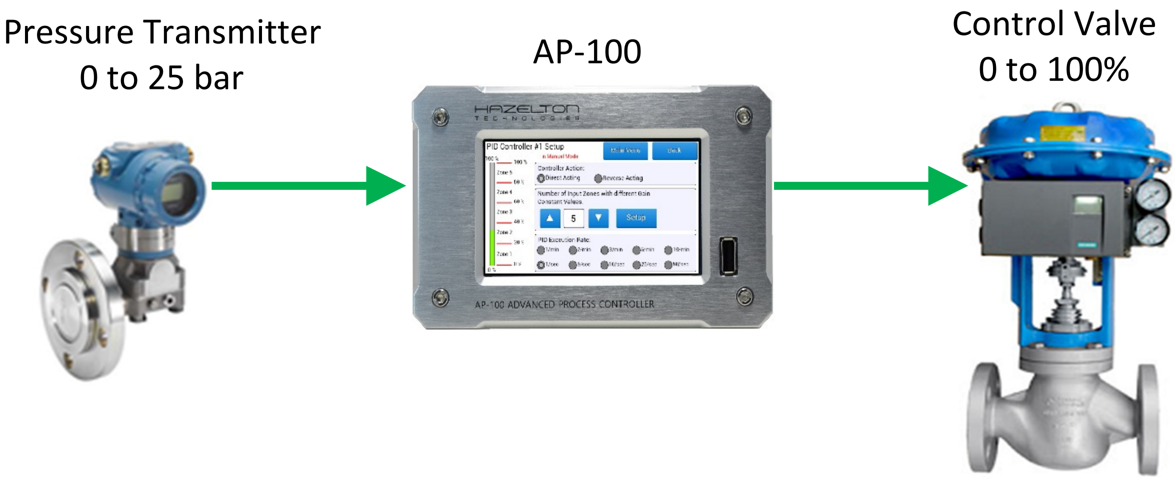
This allows for better overall performance of the PID controller of the full Input signal range. Note that the current value of the Set-Point is not shown on the PID controller setup screen, this is shown and set on the Operator screen, see Section 9.

8.4. Controller Ranging

Both PID Controllers #1 and #2 use percentage (%) as the standard metric. Therefore, the controller's signals; Input, Set-Point and Output are in percent (%) with range from 0.00% to 100.00%. If the AP-100 device is reading a signal input from a pressure transmitter with range 0 to 25 bar, into Analogue Input Channel #1. But the PID Controller #1 is configured with an input range of 20 bar as 0.00% and 25 bar as 100.00%, then an Equation must be used to scale the input signal to the 0.00 – 100.00% range of the PID Controller #1 (See Section 6 for information on Equations).

Equation #1: PID1.IN = 20 * AI1 – 400

Any value that is assigned to PID1.IN that is below 0.00 shall be registered as 0.00%. Any value that is assigned to PID1.IN that is above 100.00 shall be registered as 100.00%.



To assign the Output signal of PID Controller #1 to Analogue Output Channel #1, to control a control valve, use the below equation.

Equation #2: AO1 = PID1.OUT

8.5. P, I and D Gain Constants

PID Controllers take action based on the difference between the Input signal and the Set-point. This is known as the Error signal which is shown below. The Error can be a positive or negative number between -100.00 % and +100.00%.

$$Error(\%) = Setpoint(\%) - Input(\%)$$

The Error signal can be thought of the difference between the desired process value (Set-Point) and the actual read process value (Input Signal). A PID control produces an updated Output signal every execution based on the following gain constant. The three gain constants that can be configured for each zone, as shown in the previous sections, are:

- Proportional Gain - P_{gain} is measured in percent (%).
- Integral Gain – I_{time} is measured in controller execution cycles.
- Derivative Gain – D_{time} is measured in percent (%).

Each of the above gain constants have their own multiplying effect on the Error signal. The result of these multiplications are then summed together during each controller execution cycle to produce the new Output signal value. This is shown in the below equation:

$$PID.OUT(\%) \ = \ P_{gain}\left(Error \ + \ \frac{1}{I_{time}}\int Error \ dt \ + \ \frac{D_{time}}{dt} \times \frac{d\,PID.IN}{dt}\right)$$

The above equation in discrete time format this is implemented within the AP-100 device is as follows:

$$PID.OUT(\%) \ = \ PID.OUT_{n-1} \ + \ P_{gain}\left((PID.IN_{n-1} \ - PID.IN_{n}) \ + \ \left(\frac{\Delta T}{I_{time}} Error_{n}\right) \ + \ \frac{D_{time}}{\Delta T} \times (PID.IN_{n} + \ 2 \times PID.IN_{n-1} + \ PID.IN_{n-2})\right)$$

Where:

ΔT being the 'PID Execution Rate', (i.e. '2/min' equating to 30 seconds)

$PID.IN_n$ is the current Input signal value in percent (%).

$PID.IN_{n-1}$ is the previous Input signal value in percent (%).

$PID.IN_{n-2}$ is the previous, previous, Input signal value in percent (%).

$PID.OUT_{n-1}$ is the previous Output signal value in percent (%).

8.5.1. Proportional Gain

Proportional gain (P_{gain}) value that is entered in the 'Gain Look-Up Table', is multiplied by the Error (+/-%) signal value every controller execution cycle. The controller execution cycle occurs according to the 'PID Execution Rate' which is described in Section 8.2. For a larger Proportional response, the user should enter a larger value of P_{gain} into 'Gain Look-Up Table'. For a smaller Proportional response, the user should enter a smaller value of P_{gain} into 'Gain Look-Up Table'.

8.5.2. Integral Time

The Integral time value (I_{time}) is closely linked the 'PID Execution Rate' that is selected. The Integral response is the number of controller execution cycles that shall pass for the controller to 're-apply' the P_{gain} to the Error signal. For example; if the 'PID Execution Rate' has the '5/sec' radio button selected and the I_{time} = 10 for a given zone. Integral response shall 're-apply' the P_{gain} of 2, to the Error signal every:

T = 5/sec × 10 = 0.2 seconds × 10 = 2 seconds

If the user wants a slow integral response, the user should enter a large value of I_{time} into 'Gain Look-Up Table'. If a fast response is desired, the user should enter a smaller value of I_{time} into 'Gain Look-Up Table'. If the user would prefer not to use Integral response, simply enter a very large value for I_{time}.

8.5.3. Derivative Time

The contribution of the Derivative response to the controller's Output is based upon the rate of change (derivative) of the product of controller gain (P_{gain}) times the Error signal. The tuning parameter, D_{time}, allows the user to adjust the relative effect of this mode of control.

The derivative of the Error is calculated by determining the slope (or gradient) of the Error over time and multiplying this rate of change by the derivative gain D_{gain}. The derivative gain D_{gain} is closely linked the ‘PID Execution Rate’ that is selected, as shown below. For example, if the ‘PID Execution Rate’ has the ‘5/sec’ radio button selected and the D_{time} = 0.5 for a given zone.

$$D_{gain} = \frac{D_{time}}{\Delta T} = \frac{0.5}{5/sec} = \frac{0.5}{0.2} = 2.5$$

In general, a large Derivative time D_{time} should not be used in control loops in which there is an excessive amount of noise on the measurement. This is because the predictive nature of derivative would amplify the noise and cause an excessive amount of noise on the controller output. This will eliminate most flow and level loops, and possibly others as well Plants probably do not need to use derivative to speed up the response of loops that already have a relatively fast response. This fact will eliminate flow loops, gas-pressure loops, and possibly others from consideration for derivative control.

Process control problems such as temperature loops, or loops that have relatively noise-free and relatively slow response, as the primary candidates for the use larger values of Derivative time D_{time}. These likely include temperature and composition loops, but may also include other types of loops with similar attributes. With open-loop unstable processes such as exothermic reactors, the temperature controller will practically always use the derivative mode to stabilize the otherwise unstable process.

Warning

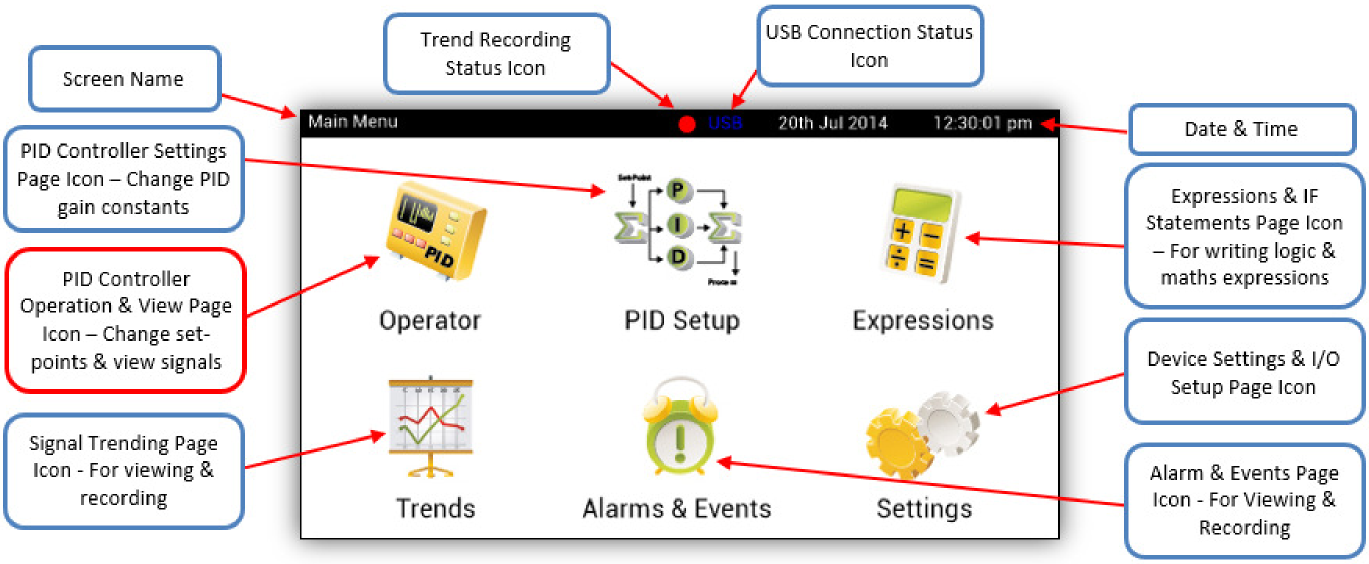
- Before making setting changes to an online system first consider how this change effects associated outputs.
- It may be necessary to shutdown plant or equipment before making this change.

9. OPERATOR SCREEN

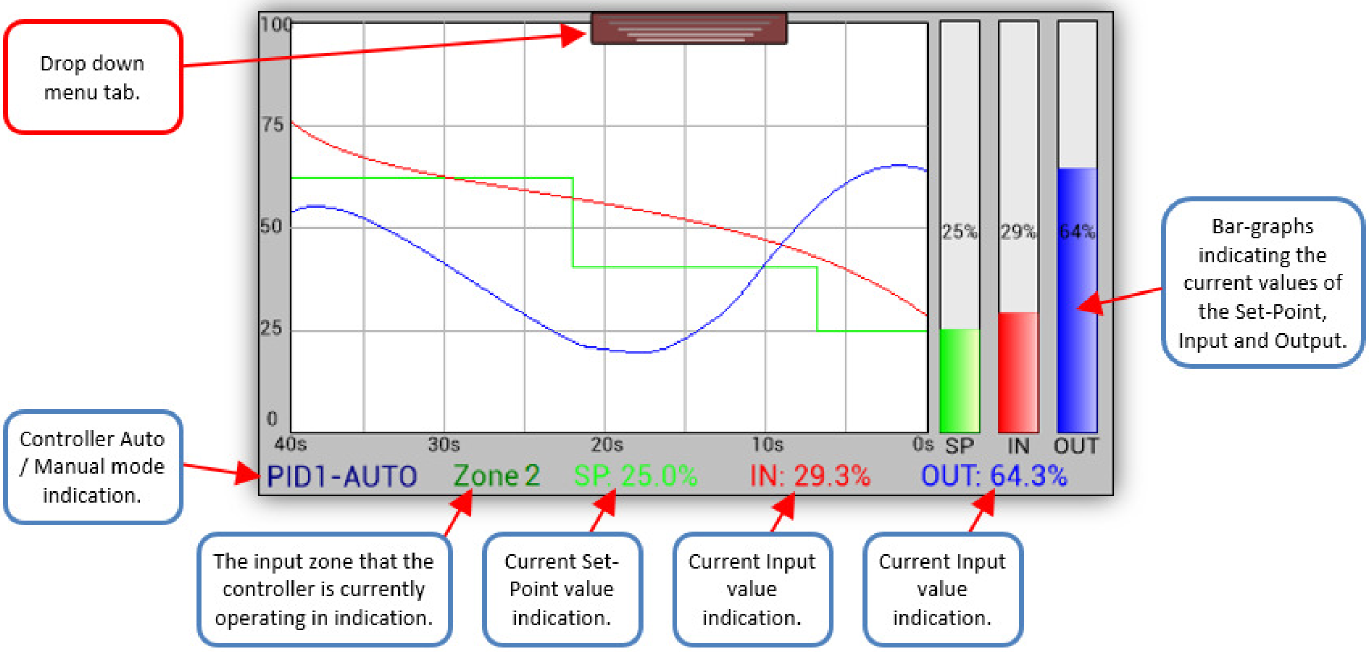
The Operator screen is the main user interface to controlling both PID Controllers #1 and #2 (see Section 8). It is where the user can do the following:

- Enter a Set-Point for both PID controllers
- Set each PID controller to Automatic mode or Manual mode.
- Manually enter an output value for each PID controller (when that controller is in Manual mode).
- View graphical information of present and previous values for controller Inputs, Outputs and Set-Points.

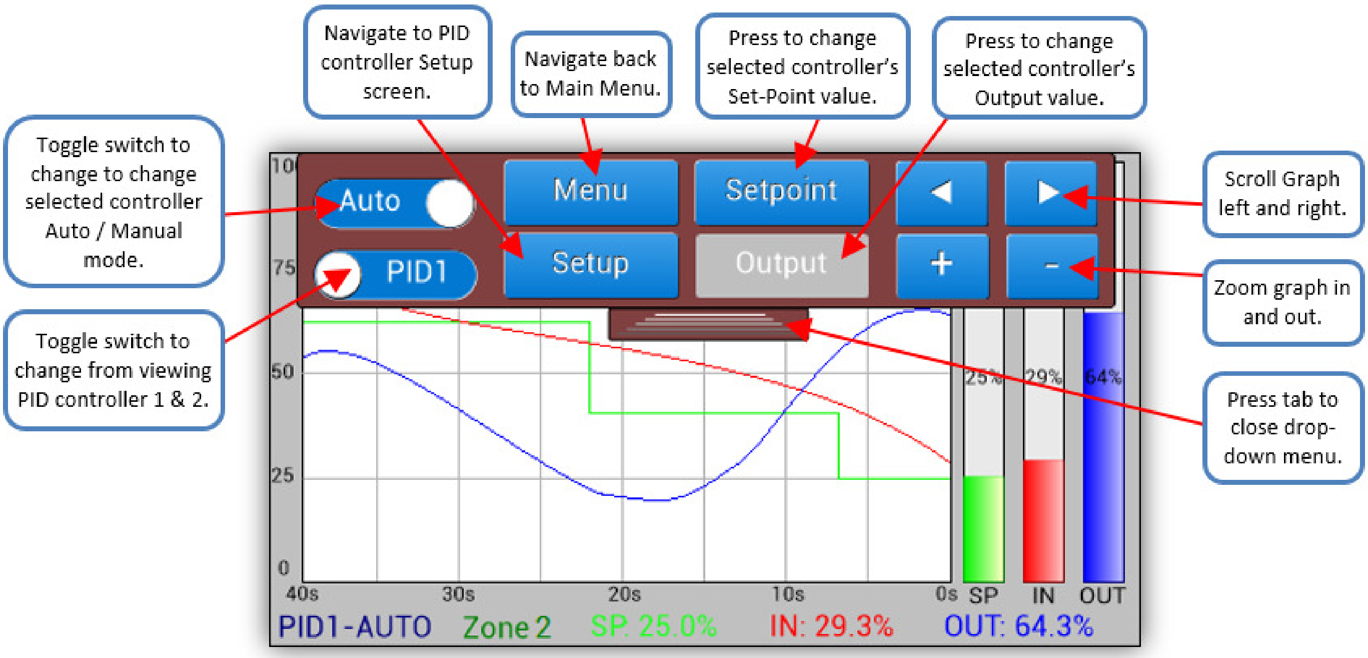
To navigate to the Operator screen from the Main Menu, simply press the 'Operator' icon as shown below.



Below shows the Operator screen. Notice the indication text at the bottom and the colour graphic plotting of the Set-Point, Input and Output signals. Also the currently Input Zone that is being executed is displayed. To show the 'Drop-down Menu' press the tab at the top.



Below show's the Operator screen with the 'Drop-down Menu'. To hide the 'Drop-down Menu' simply press the tab again. The screen refresh rate is roughly 4 times per second, however the PID controller's execution rate is many times faster (up to 50 times per second). The below graph data is recordable, see Section 10.



9.1. PID Controller Select

The AP-100 Advanced Process Controller has two PID controllers #1 and #2. To view the signal data and control each PID controller press the toggle button as shown above. The graphical data shall change and to verify which controller the user is currently viewing, simply look at the bottom left text.

9.2. Auto / Manual Mode

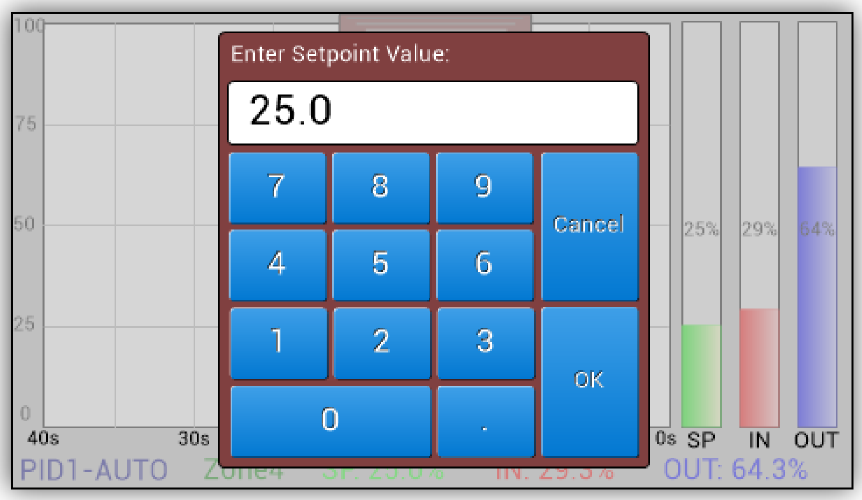
Use the toggle switch at the top left to change the selected PID controller 'Auto' or 'Manual' mode. To verify which mode, the selected PID controller is in, simply look at the bottom left text. In 'Auto' mode the PID controller shall execute according to its configuration on the 'PID Controller Setup' screen. In 'Manual' mode the PID controller shall stop executing and the Output signal shall hold its last value. When a PID controller is in 'Manual' mode the user can manually change the Output signal value.

9.3. Scrolling and Zoom

The graphical data can be scrolled in time left and right, using the arrow buttons indicated above. The Graph can also be zoomed in and out, using the + and – buttons, to view a wider view of graphing information. Changing PID controller's resets the current graph view for convenience.

9.4. Changing PID Controller Set-Point

To change the PID controller Set-Point (%), first ensure that the desired controller is selected. Then press the 'Setpoint' button as shown above. This shall display a keypad for the user to enter a new Set-Point value as shown below. When finished press the 'OK' button to accept and save, or 'Cancel' button to exit without making changes. Note that if the selected PID controller is has its 'PID1.SP' signal assigned in an Equation (see Section 6) then the user entered value shall be over-written in the next CPU execution cycle.



9.5. Changing PID Controller Output

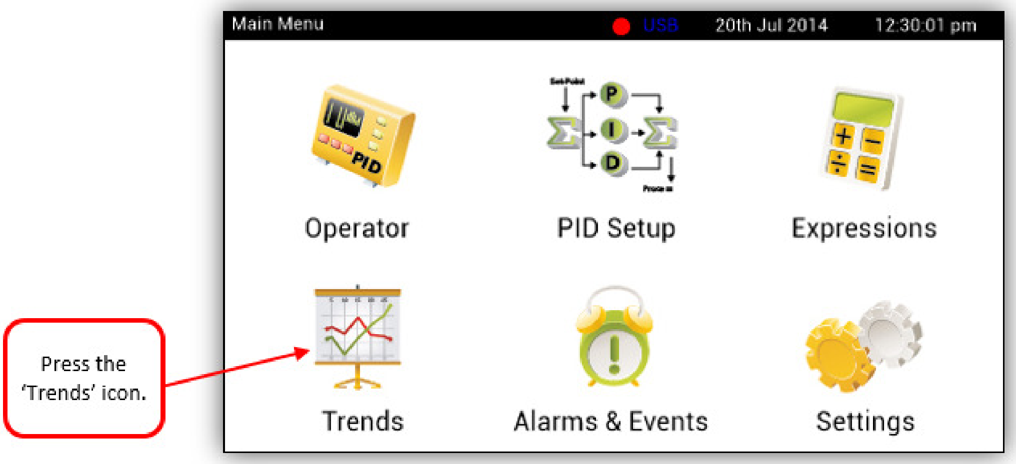
To change the PID controller Output (%), first ensure that the desired controller is selected. Then press the 'Output' button as shown above. A keypad shall appear for the user to enter a new value, just the same as when changing the Set-Point. Note that if the selected PID controller is in 'Auto' mode then the 'Output' button shall be disabled and greyed-out. To override the PID controller the user must first switch it to 'Manual' mode and then 'Output' button shall become availible.

Warning

- Before making setting changes to an online system first consider how this change effects associated outputs.
- It may be necessary to shutdown plant or equipment before making this change.

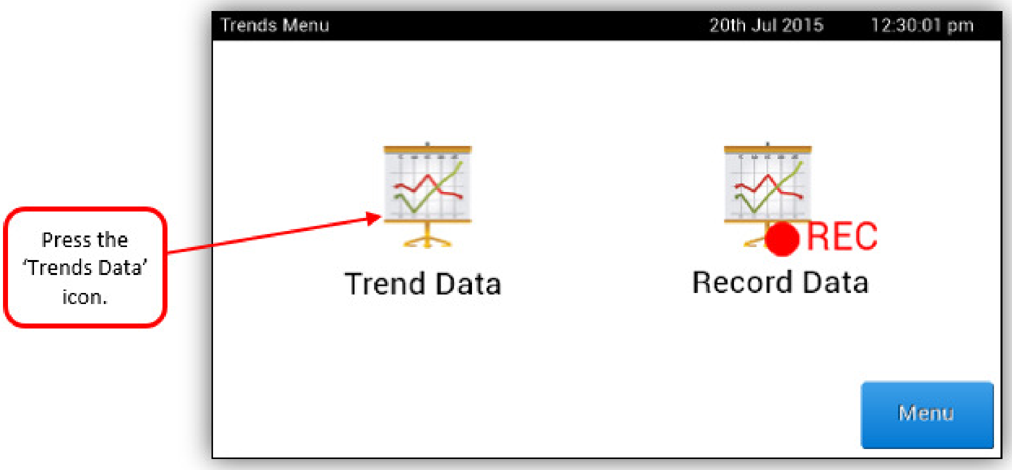
10. TRENDS

The AP-100 Advanced Process Controller is able to plot and record trends of all Inputs, Outputs and PID Controllers signals. To navigate to the 'Trends' press the 'Trends' icon as shown below from the Main Menu.

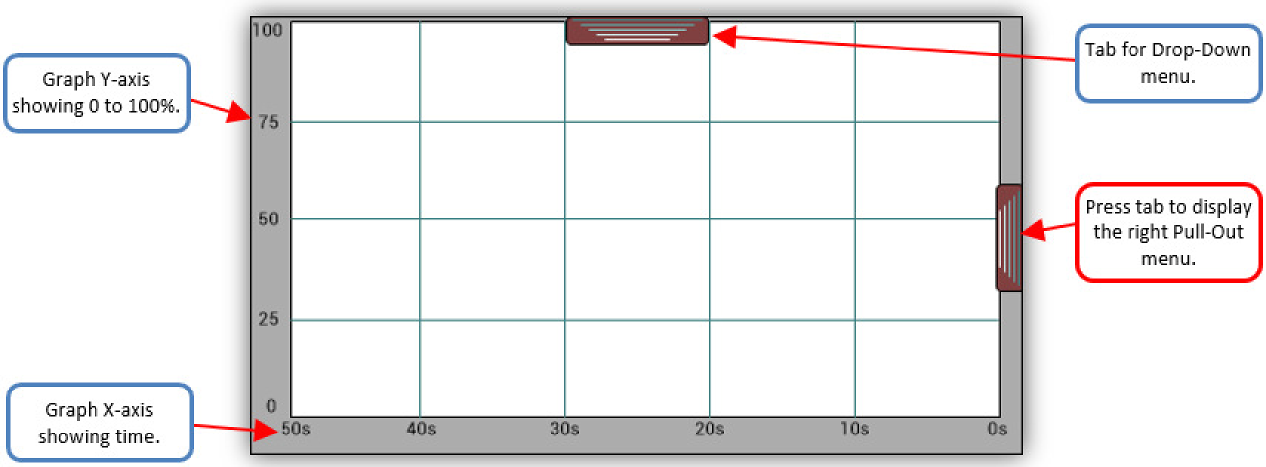


10.1. Signal Trend Graphing

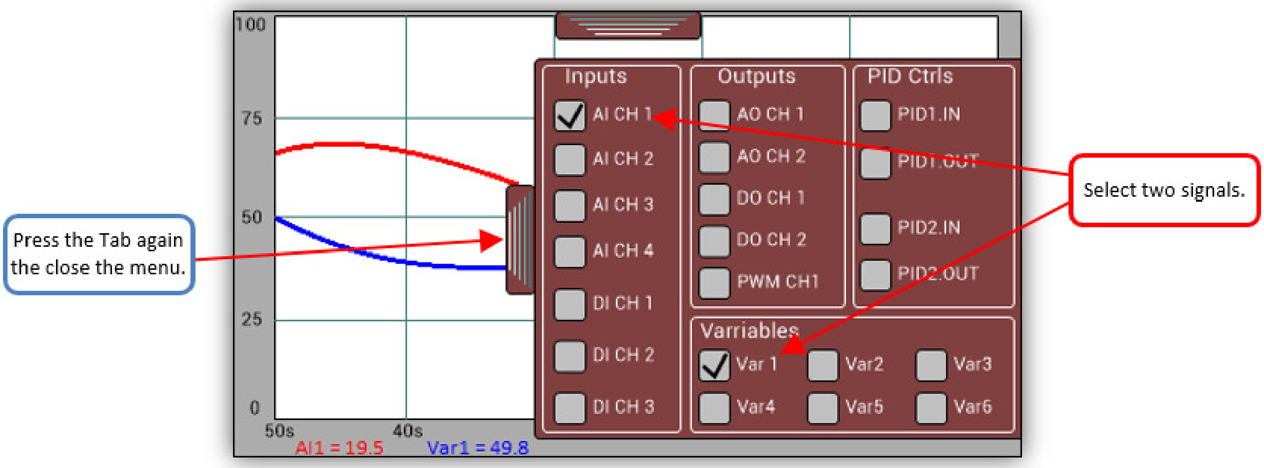
From the 'Trends Menu' screen press the 'Trend Data' icon as shown below.



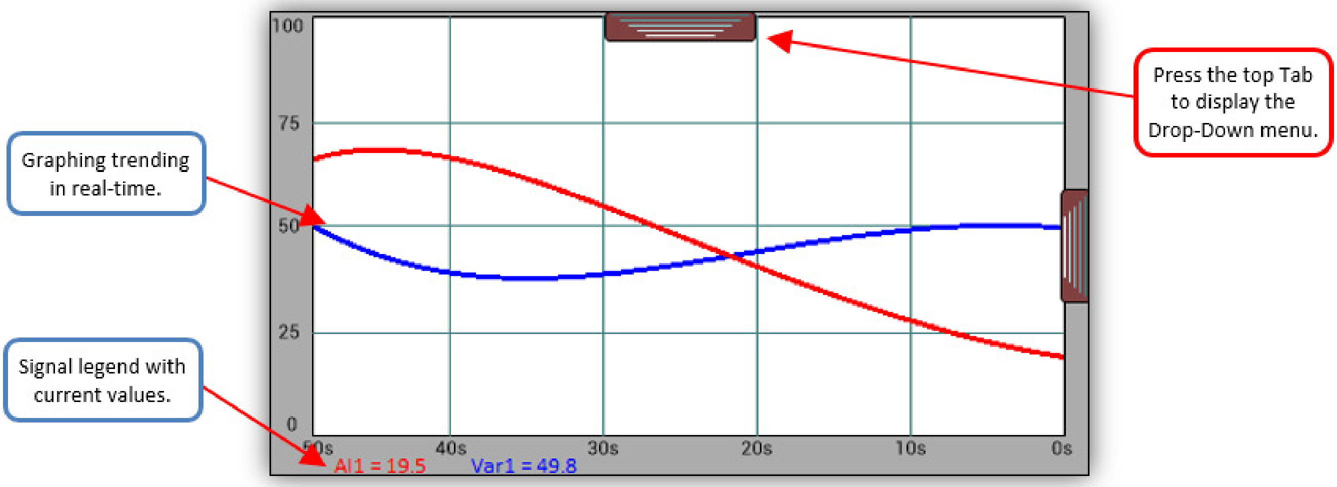
Below shows the 'Trend' without any trends selected. Notice the tab at eh top and right side, pressing these will display the respective menu screens. To select graphs for trending, press the tab on the right to display available signals for trending.



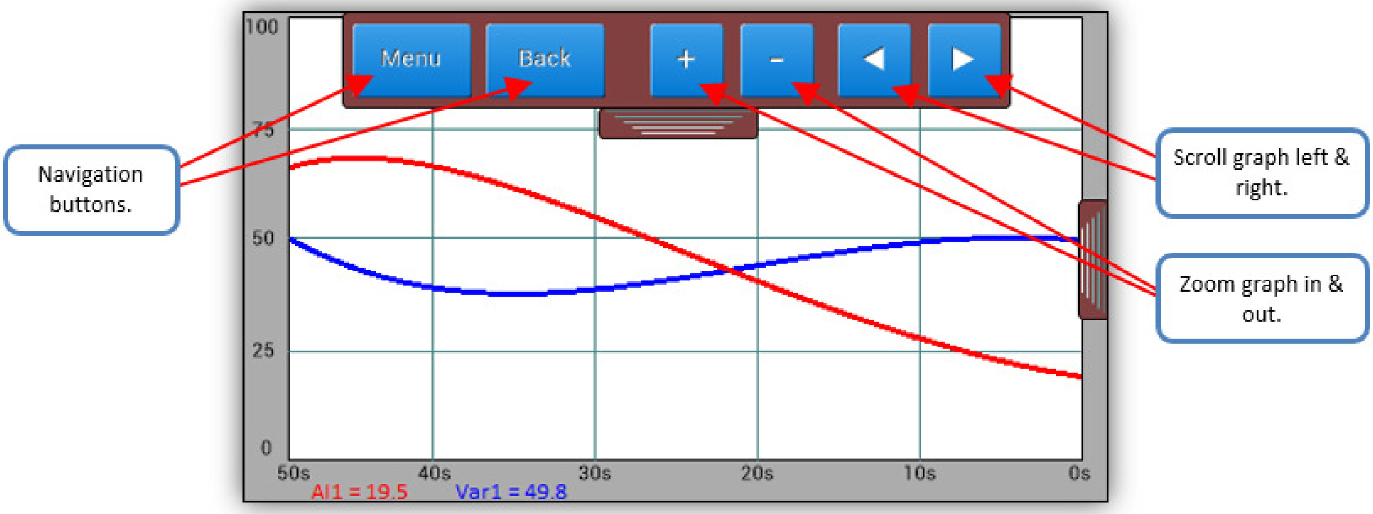
As shown below, the right Pull-Out menu contains checkboxes for each of the signals that can be trended. In the below the Analogue Input Channel 1 and Intermediate Variable #1 have been selected. Pressing the Tab again will close this menu.



The below shows the graphical data being trended in real-time. The legend at the bottom identifies each graph and displays the current values. Press the top tab to display the Drop-Down menu.

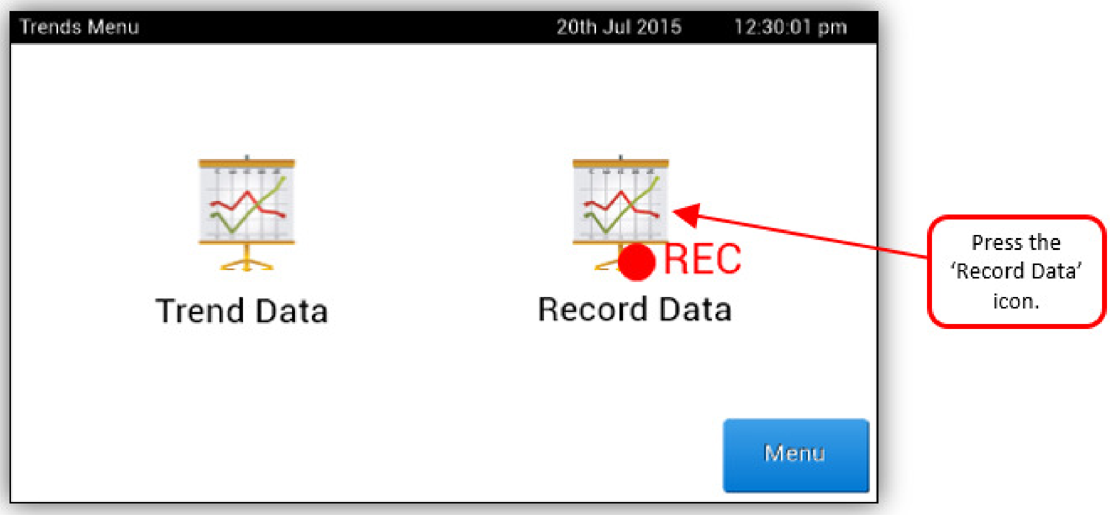


As shown below, the Drop-Down menu displays additional controllers for scrolling the graph left and right (forward back with respect to time). Also in and out with respective to time.

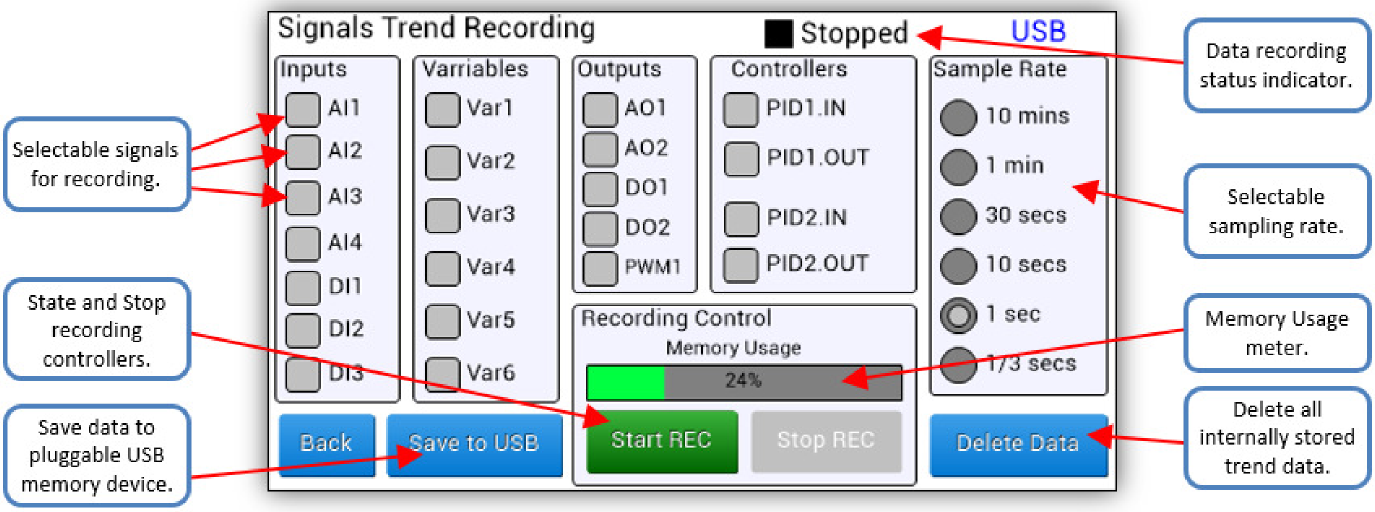


10.2. Recording Trend Data

The AP-100 device is able to record signal trend data to internal non-volatile memory. The saved trend data can later be saved to a pluggable USB memory drive that is inserted into the front of the AP-100 device. To navigate the 'Signals Trend Recording' screen, press the 'Record Data' icon on the 'Trends Menu' screen, as shown below.



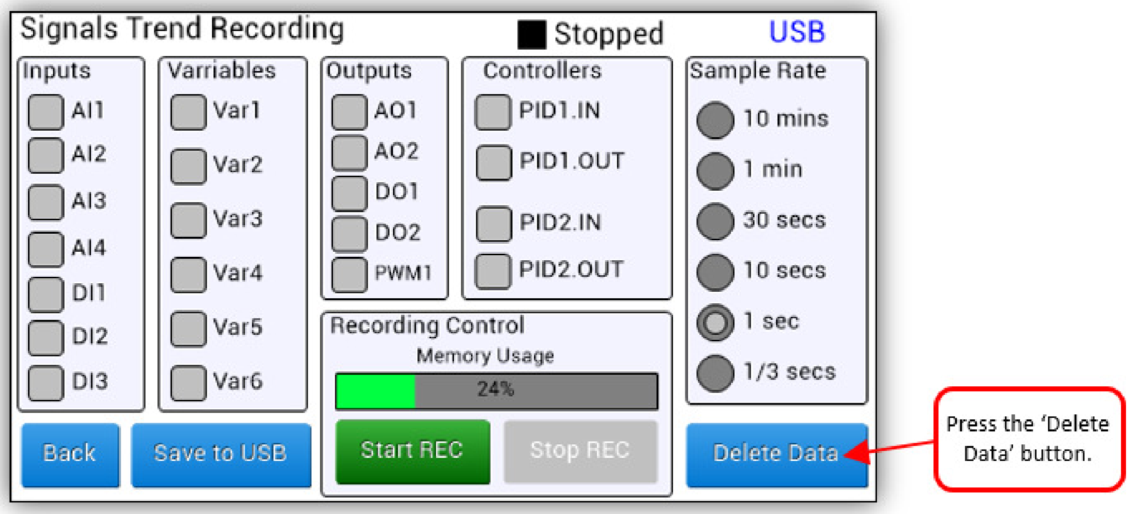
Below shows the 'Signals Trend Recording' screen. As can be seen there is a checkbox for selecting each recordable signal. The right hand side has the radio buttons for selecting the desired sampling rate. This is the rate at which the AP-100 device shall collect date and save it to memory. There is a memory meter which indicated how much memory has been used up, and 'Start' and 'Stop' recording buttons. From this screen all internal stored signal data can be Deleted or saved to pluggable USB memory drive, as indicated via the below buttons.



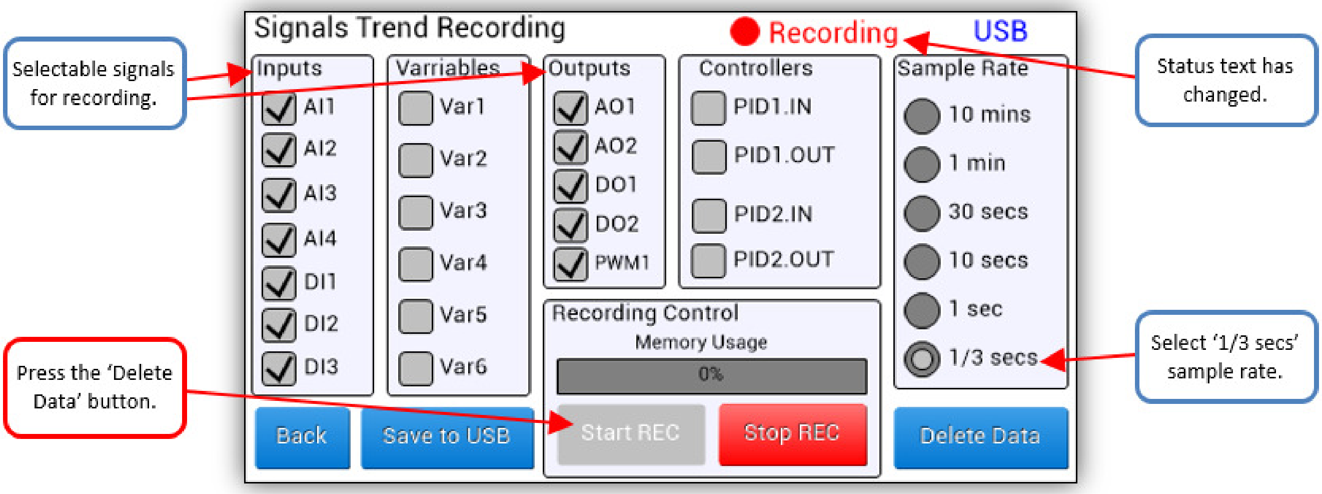
Example: Setup Signals for trending

In the following example the all currently stored trend data shall be deleted. Then the AP-100 device shall be setup to record all input and output signals at a 1/3 second sample rate. Then the stored data shall be save to an inserted USB memory drive.

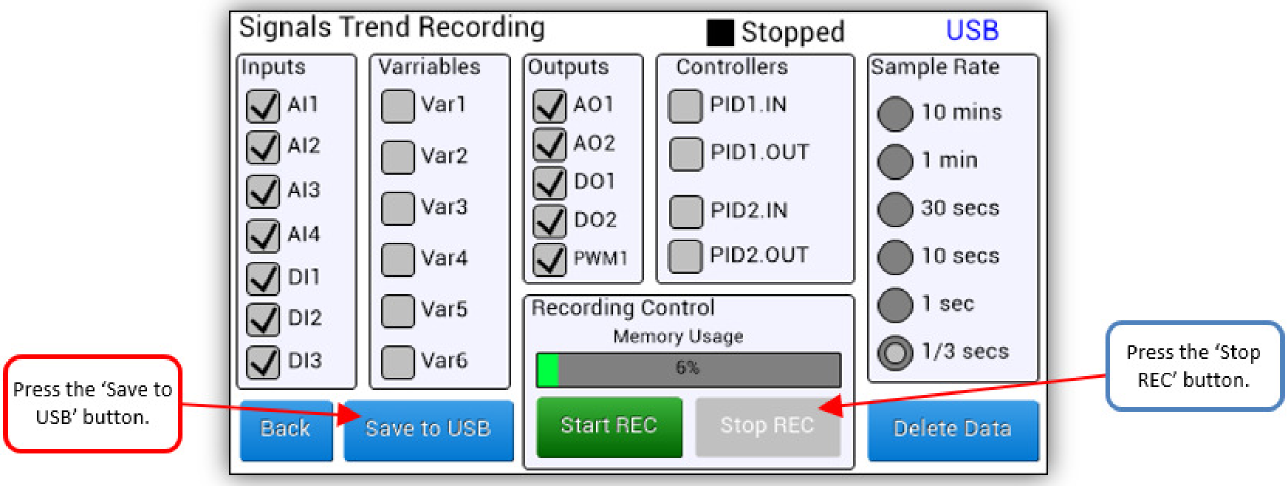
As shown below, press the 'Delete Data' button to delete all currently saved signal trend data. A pop-up message box shall appear, press 'Yes' to confirm the deletion of the data.



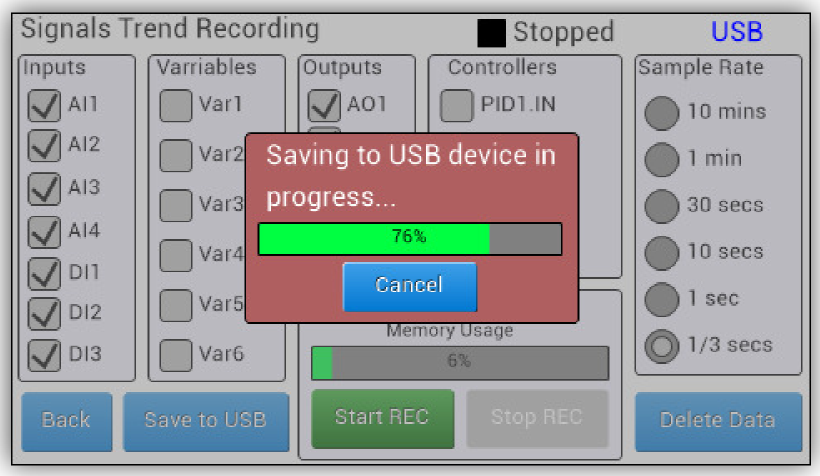
As can be seen below the memory usage meter has now gone to 0% and the entire memory bank is available to record new data. Select all Input and Output signal checkboxes, and the sample rate of '1/3 secs'. To start recording press the green 'Start REC' button. Notice that the status text at the top of the screen and changed. The user can now navigate away from this screen can come back it is desired to stop recording or to change these settings.



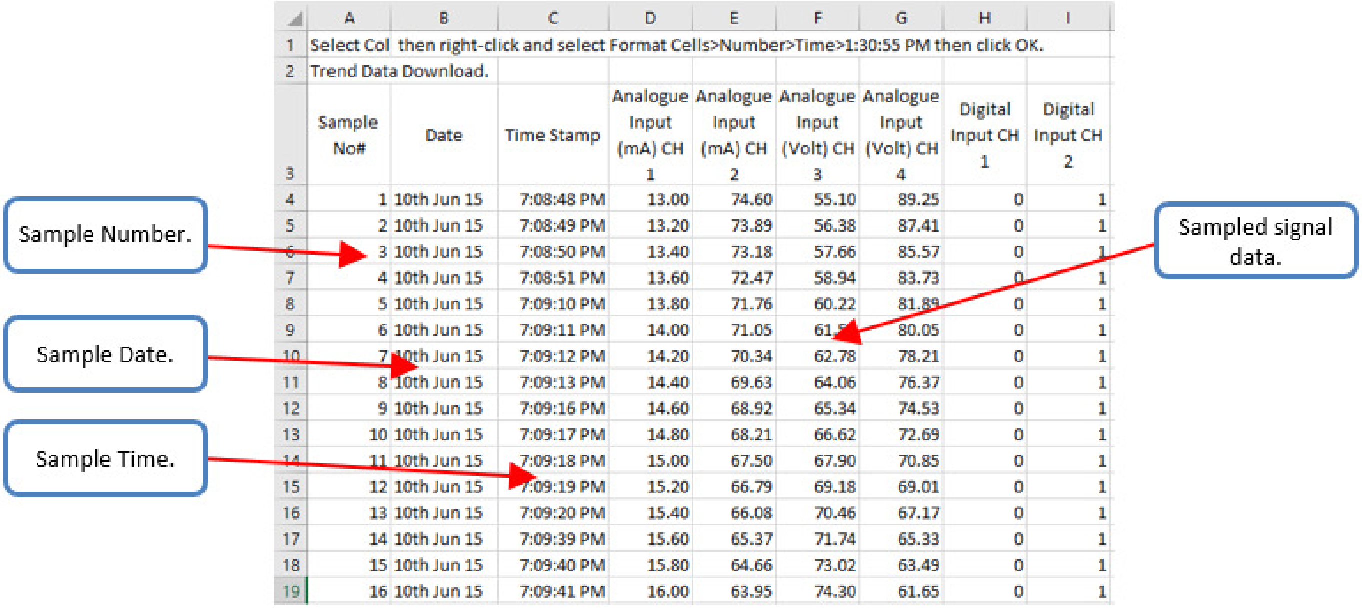
After the enough data has been recorded, press the 'Stop REC' button as shown below. Then ensure that a USB memory drive is inserted into the front of the AP-100 device and then press the 'Save to USB' button.



The AP-100 device shall save the trend signal data as a .csv file to the main directory of the USB memory drive. The file name stall be time of when the data was saved.



The saved .csv file on the USB memory drive can be opened in MS Excel or any similar spreadsheet program. As shown below the signal data is displayed with the time and date on the left. From here the data can be filtered or graphed for further analysis.



Select Col then right-click and select Format Cells>Number>Time>1:30:55 PM then click OK.

Trend Data Download.

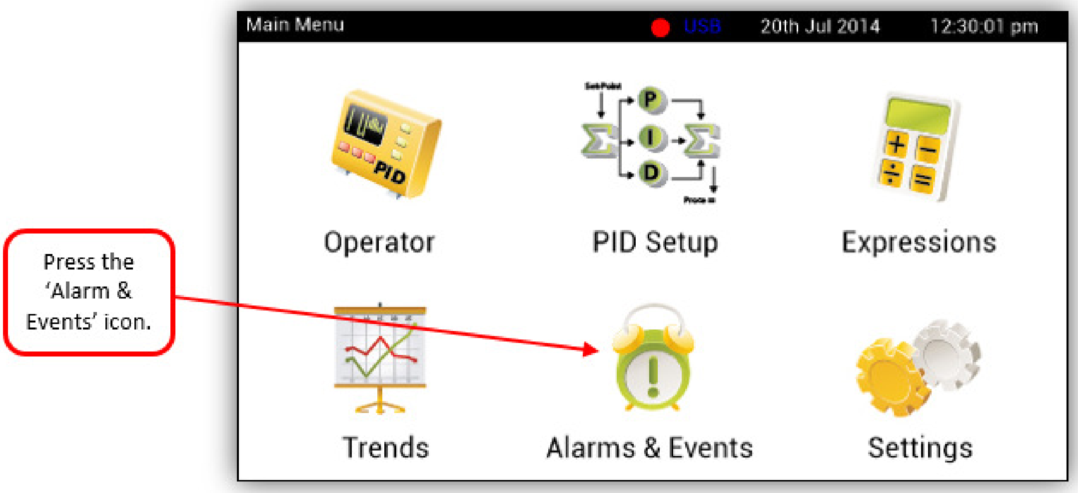
Sample No#	Date	Time Stamp	Analogue Input (mA) CH 1	Analogue Input (mA) CH 2	Analogue Input (Volt) CH 3	Analogue Input (Volt) CH 4	Digital Input CH 1	Digital Input CH 2
1	10th Jun 15	7:08:48 PM	13.00	74.60	55.10	89.25	0	1
2	10th Jun 15	7:08:49 PM	13.20	73.89	56.38	87.41	0	1
3	10th Jun 15	7:08:50 PM	13.40	73.18	57.66	85.57	0	1
4	10th Jun 15	7:08:51 PM	13.60	72.47	58.94	83.73	0	1
5	10th Jun 15	7:09:10 PM	13.80	71.76	60.22	81.89	0	1
6	10th Jun 15	7:09:11 PM	14.00	71.05	61.5[illegible]	80.05	0	1
7	10th Jun 15	7:09:12 PM	14.20	70.34	62.78	78.21	0	1
8	10th Jun 15	7:09:13 PM	14.40	69.63	64.06	76.37	0	1
9	10th Jun 15	7:09:16 PM	14.60	68.92	65.34	74.53	0	1
10	10th Jun 15	7:09:17 PM	14.80	68.21	66.62	72.69	0	1
11	10th Jun 15	7:09:18 PM	15.00	67.50	67.90	70.85	0	1
12	10th Jun 15	7:09:19 PM	15.20	66.79	69.18	69.01	0	1
13	10th Jun 15	7:09:20 PM	15.40	66.08	70.46	67.17	0	1
14	10th Jun 15	7:09:39 PM	15.60	65.37	71.74	65.33	0	1
15	10th Jun 15	7:09:40 PM	15.80	64.66	73.02	63.49	0	1
16	10th Jun 15	7:09:41 PM	16.00	63.95	74.30	61.65	0	1

11. ALARM & EVENTS

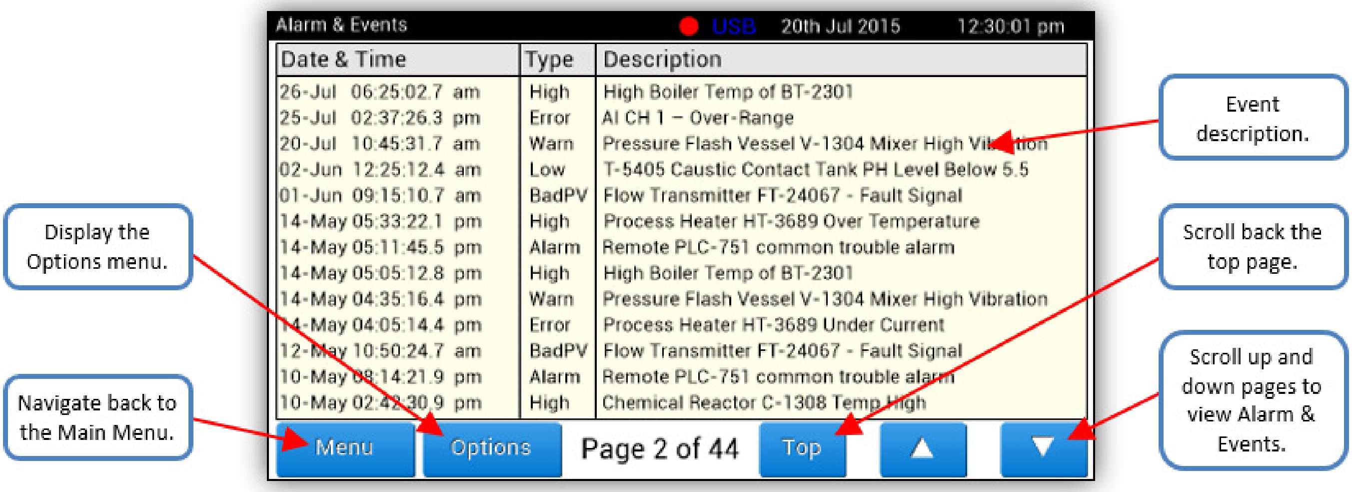
The AP-100 Advanced Process Controller is able log and store alarm and events to internal non-volatile memory that can be later saved to a USB memory drive and then open and viewed on a personal computer with any spreadsheet program.

Alarm & Events can be configured from the analogue & digital input values (see Analogue & Digital Input Channels Setup – Section 4) or from an IF Statement (see If Statement Setup – Section 7).

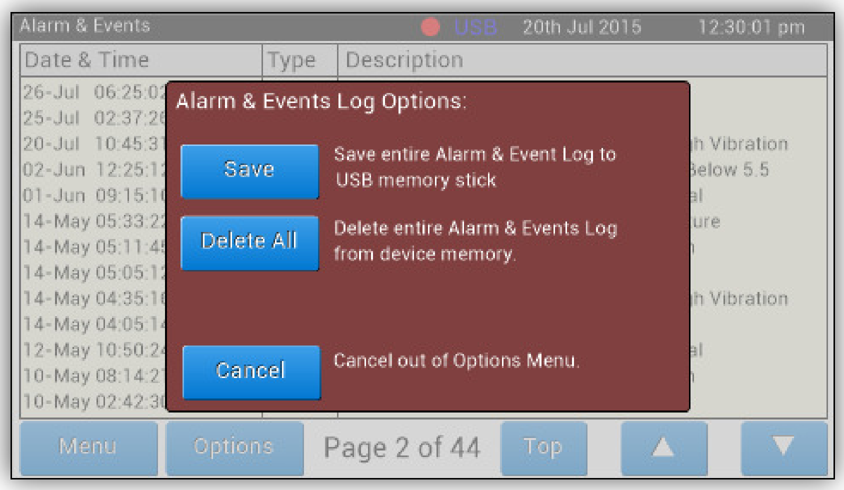
To navigate to the ‘Alarms & Events’ screen, press the icon as shown below from the Main Menu.



Below shows the ‘Alarm & Event’ screen populated with alarm and events. Alarm & Events can be viewed by scroll through the pages with the up and down arrow buttons. To Display the ‘Options Menu’ press the ‘Options’ button.

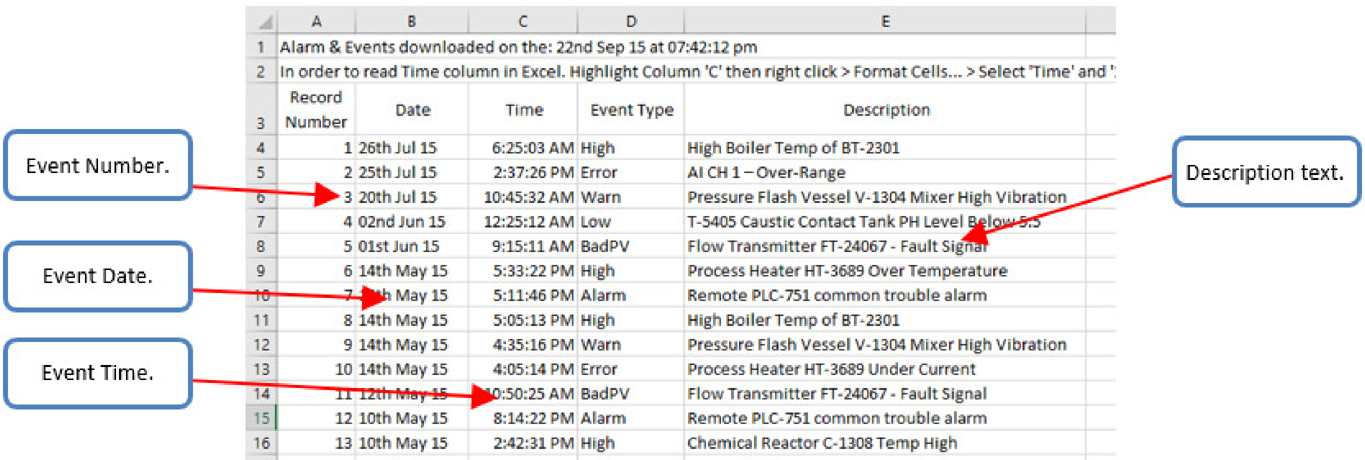


As shown below, the options menu enables the user to save all data to a USB memory drive or the delete all internally stored data.



To save all Alarm & Event data, simply insert a USB memory drive and then press the save button. A progress bar shall be displayed to show the saving progress. The Alarm & Event data shall be saved to the main directory on the USB memory drive, with the file name being the date of the save.

The saved .csv file on the USB memory drive can be opened in MS Excel or any similar spreadsheet program. As shown below the Alarm & Event data is displayed with the time and date on the left. From here filters may be used to further analyse the data.



	A	B	C	D	E
1	Alarm & Events downloaded on the: 22nd Sep 15 at 07:42:12 pm				
2	In order to read Time column in Excel. Highlight Column 'C' then right click > Format Cells... > Select 'Time' and '				
3	Record Number	Date	Time	Event Type	Description
4	1	26th Jul 15	6:25:03 AM	High	High Boiler Temp of BT-2301
5	2	25th Jul 15	2:37:26 PM	Error	AI CH 1 – Over-Range
6	3	20th Jul 15	10:45:32 AM	Warn	Pressure Flash Vessel V-1304 Mixer High Vibration
7	4	02nd Jun 15	12:25:12 AM	Low	T-5405 Caustic Contact Tank PH Level Below 5.5
8	5	01st Jun 15	9:15:11 AM	BadPV	Flow Transmitter FT-24067 - Fault Signal
9	6	14th May 15	5:33:22 PM	High	Process Heater HT-3689 Over Temperature
10	7	[illegible]h May 15	5:11:46 PM	Alarm	Remote PLC-751 common trouble alarm
11	8	14th May 15	5:05:13 PM	High	High Boiler Temp of BT-2301
12	9	14th May 15	4:35:16 PM	Warn	Pressure Flash Vessel V-1304 Mixer High Vibration
13	10	14th May 15	4:05:14 PM	Error	Process Heater HT-3689 Under Current
14	11	12th May 15	[illegible]0:50:25 AM	BadPV	Flow Transmitter FT-24067 - Fault Signal
15	12	10th May 15	8:14:22 PM	Alarm	Remote PLC-751 common trouble alarm
16	13	10th May 15	2:42:31 PM	High	Chemical Reactor C-1308 Temp High

12. SYSTEM SETUP

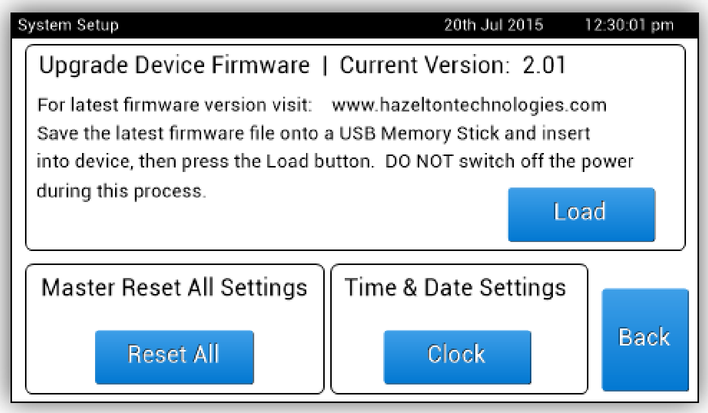
The 'System Setup' screen is where the user can perform the following:

- Set the Time & Date
- Perform a Master Reset of the entire AP-100 device
- Upgrade the AP-100 devices firmware

To navigate to the 'System Setup' screen, press the 'Settings' icon from the Main Menu.

From the 'Settings Menu' screen, press the 'System Setup' icon as shown below.

The 'System Setup' screen is shown below.



12.1. Master Reset

As shown above, press the 'Reset All' button to erase all setting s and to revert the AP-100 device to its default factory settings. A message box shall first appear to warn the user that they are about to erase all data. Press 'Yes' to continue with the erase, press 'No' to cancel and not erase any data.

12.2. Time & Date Settings

As shown above, press the 'Clock' button change the date and time.

12.3. Upgrade Device Firmware

The AP-100 Advanced Process Controller has the ability to upgrade its own firmware to add additional features and functionality. To upgrade the firmware, use the following procedure:

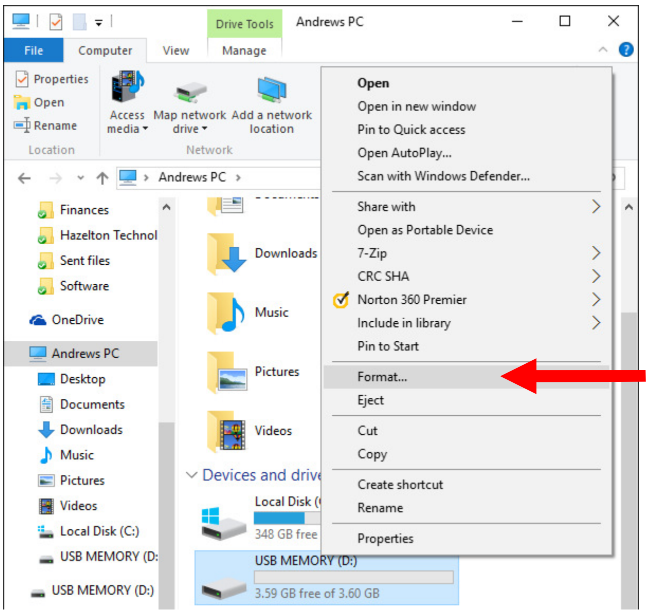
1) Ensure that any equipment that the AP-100 is controlling is shutdown. Performing a firmware upgrade shall cause all other AP-100 functions to cease (i.e. PID Controllers, Equations, Trending, Input and Output reading and writing).

Warning

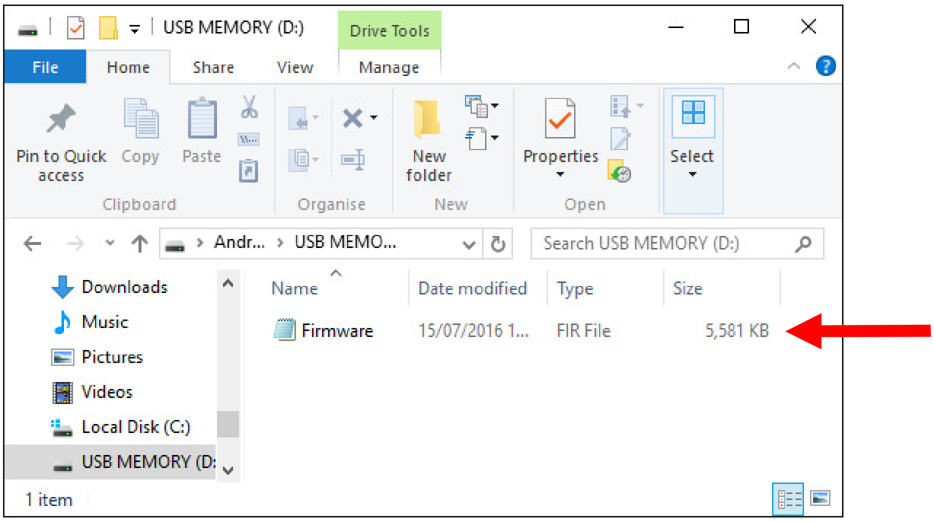
- Before making setting changes to an online system first consider how this change effects associated outputs.
- It may be necessary to shutdown plant or equipment before making this change.

2) To obtain the latest AP-100 device firmware, visit the webpage www.hazeltontechnologies.com and download the latest firmware file. As shown above, the currently installed firmware revision is shown, for this example the current firmware revision is 2.01.

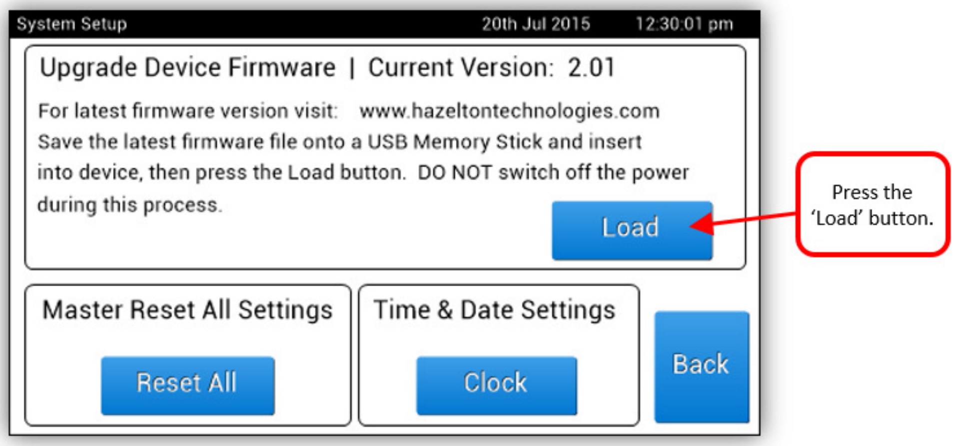
3) Take a USB memory drive and format it for FAT32.



4) Save the new firmware file to the USB memory drive with the name “Firmware.FIR”. Do not change the name of the firmware file.



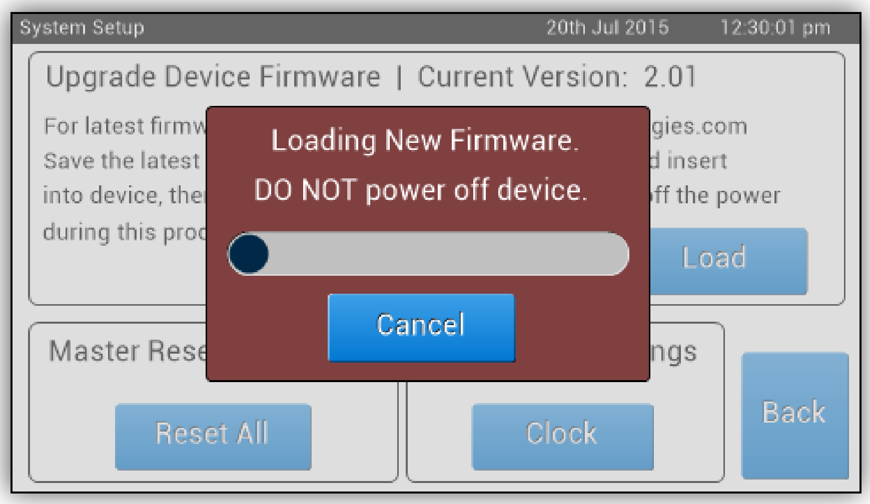
5) Insert the USB Memory Drive into the front of the AP-100 device.



Warning

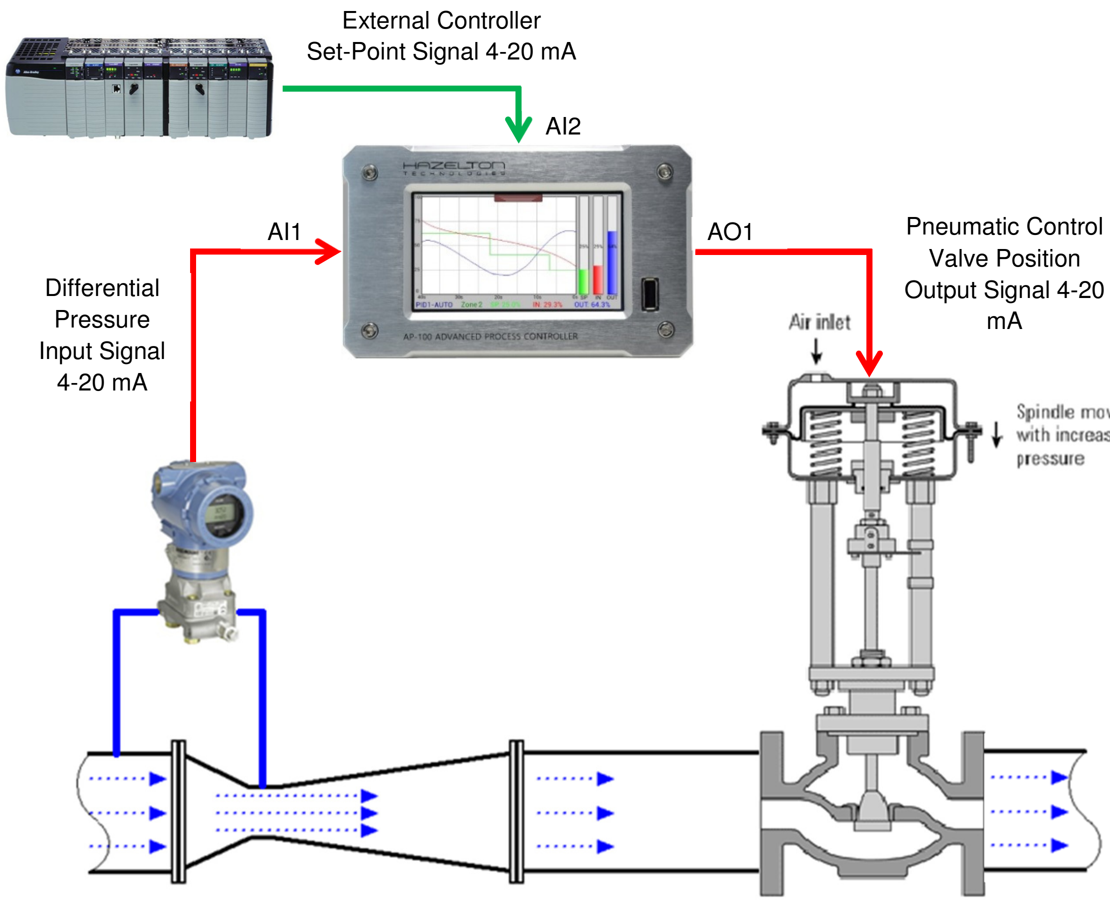
- DO NOT power off the AP-100 device whilst performing a firmware upgrade, as this will permanently damage the device.

6) A progress bar shall be displayed showing the progress of the firmware upgrade. This process can take up to 5 minutes. Once the upgrade is complete, the AP-100 device shall re-start and will be ready for use.



13. CASE STUDY - LIQUID CHLORINE FLOW CONTROLLER

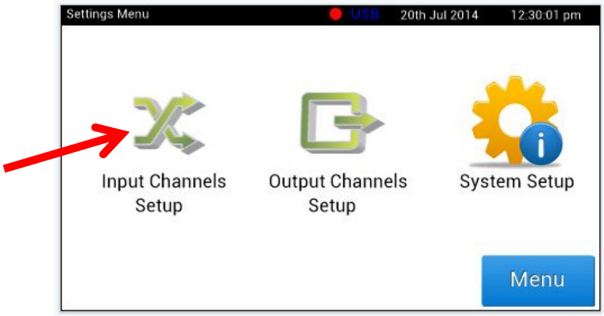
In this example, the AP-100 Advanced Process Controller shall be used as a PID flow controller for a liquid Chlorine line. The flow rate is to be measured with a venturi flow meter and differential pressure transmitter, which shall be a 4-20mA signal input into the AP-100 device. This input signal shall then be the input into the internal PID Controller to the AP-100 device. The PID Controller's Output shall drive a 4-20mA signal to a pneumatic control valve. The AP-100 device shall have a second 4-20mA input signal from an external PLC that shall be the Set-Point signal for the PID controller, as shown below.



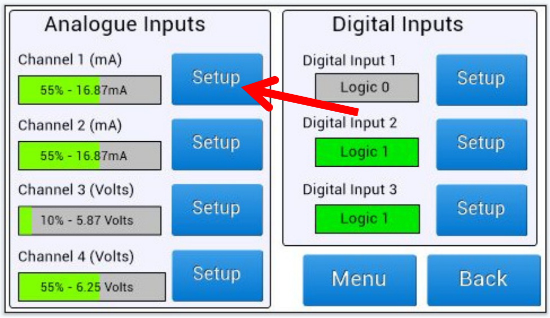
13.1. Setup Input Signals

The differential pressure transmitter outputs a 4 – 20 mA signal with a ranged of 0 to 2 bar respectively. This shall be connected to Analogue Input Channel #1 which is capable of measuring with a range of 0 – 22 mA. This input channel shall be configured by selecting the 'Settings' icon from the 'Main Menu' as shown below.

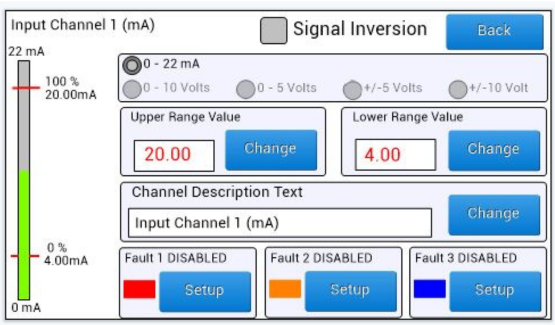
Then press the ‘Inputs Channels Setup’ icon to display the Inputs Summary page.



Press the corresponding ‘Setup’ button for the Analogue Input Channel 1.



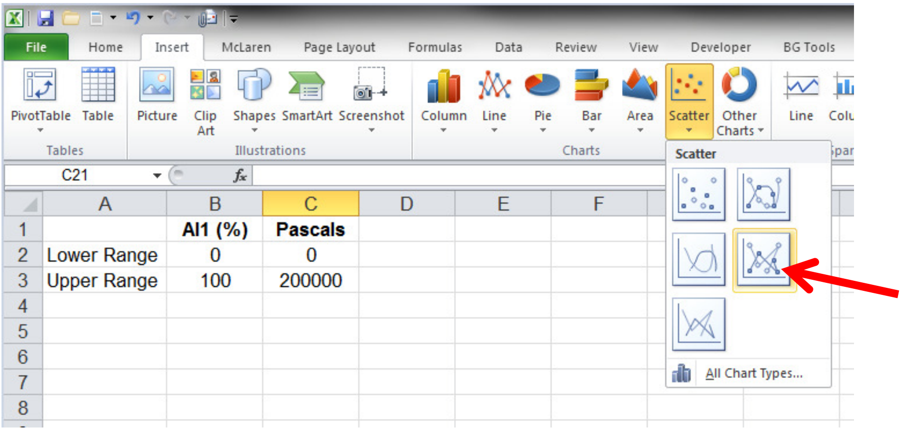
As shown below, ensure that the Upper and Lower range limits are 20.00 and 4.00 respectively. If there differ, press the corresponding ‘Change’ buttons and enter the correct value. Ensure that the ‘Signal Inversion’ check box is unchecked.



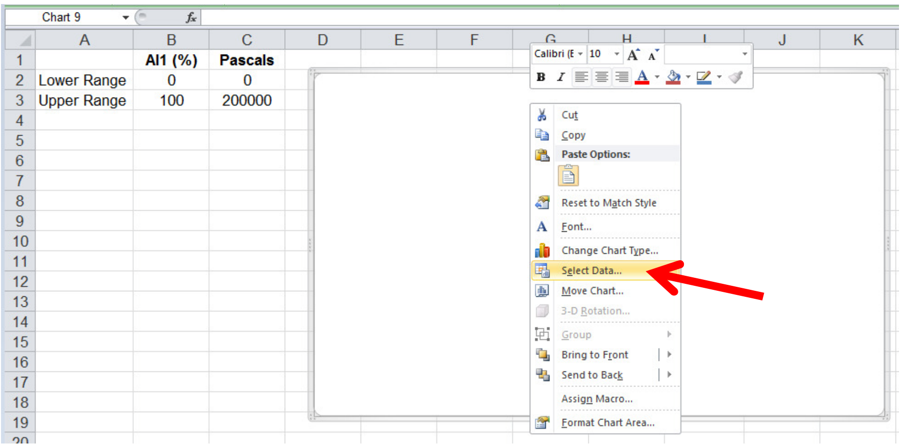
With the Analogue Input Channel 1 (AI1) setup as per the above, an input signal of 4 mA shall register as AI1 = 0.00% (which corresponds to 0 bar or 0 N/m^2).and a signal of 20 mA shall register as AI1 = 100.00% (which corresponds to 2 bar or 2×10^5 N/m^2).

Now we need to derive an equation that converts this AI1 signal of 0 – 100.00% into Pascals 0 – 2 × 10^5 N/m^2. An easy way to create this equation is to use MS Excel by first graphing these two points (Upper & Lower ranges) and then adding a linear trendline to the graph.

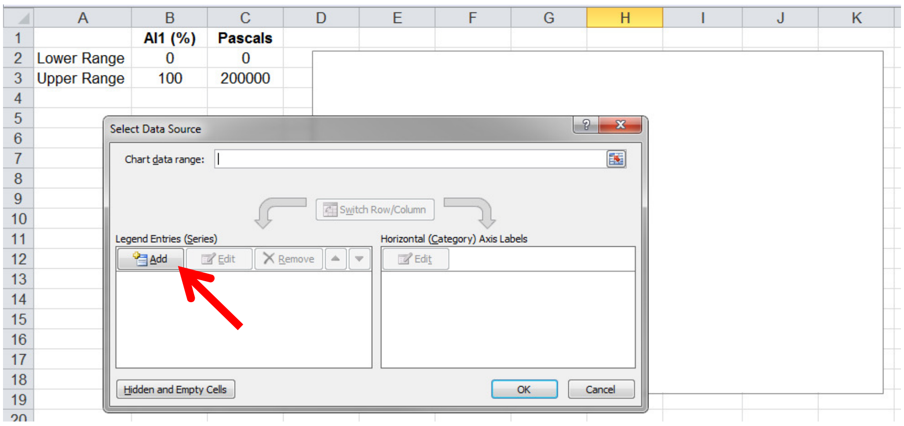
Enter the below data into MS Excel, then without highlighting any data, select from the top toolbar menu Insert > Charts > Scatter Chart.



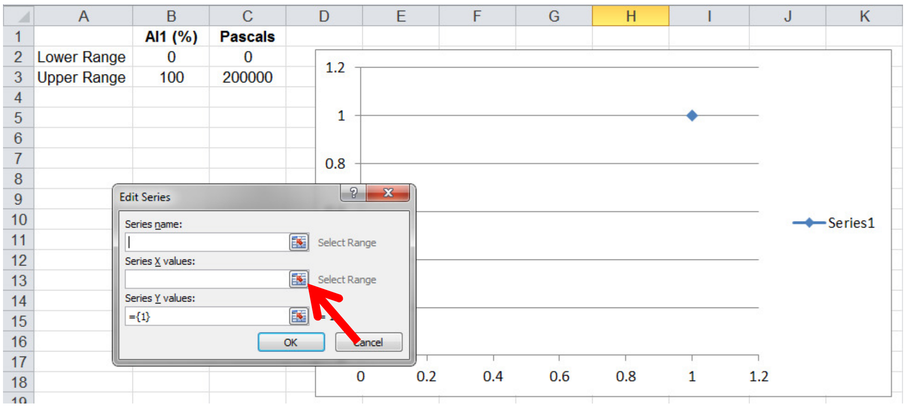
This shall display an empty graph with no data, as shown below. Right-Click on the empty graph area and chose 'Select Data…'.



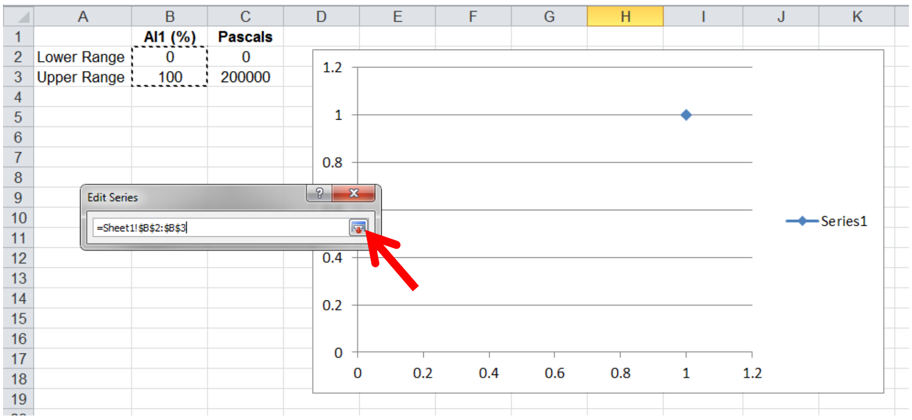
This shall display the 'Select Source Data' window. Click the 'Add' button as shown below.



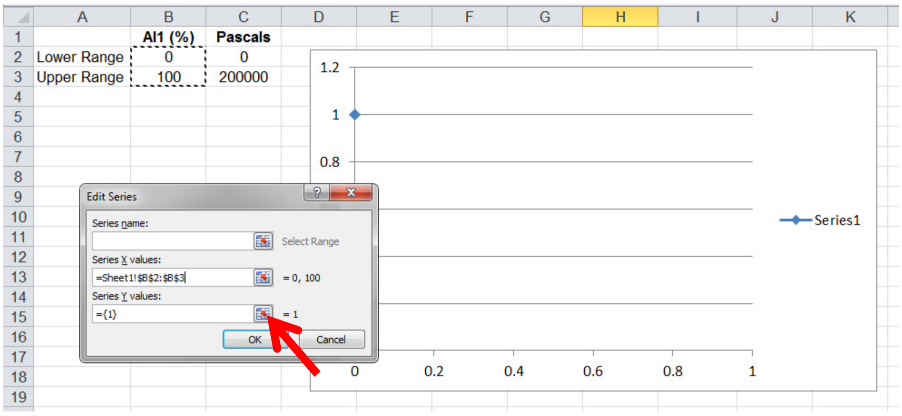
A new widow shall appear, Click on the button as shown below to add the data for the X-axis of the graph.



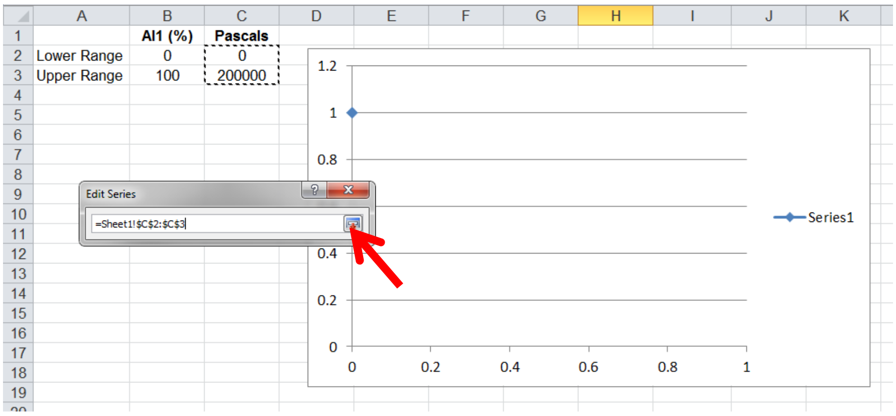
Highlight the 'AI1 (%)' data, then click the button as shown below.



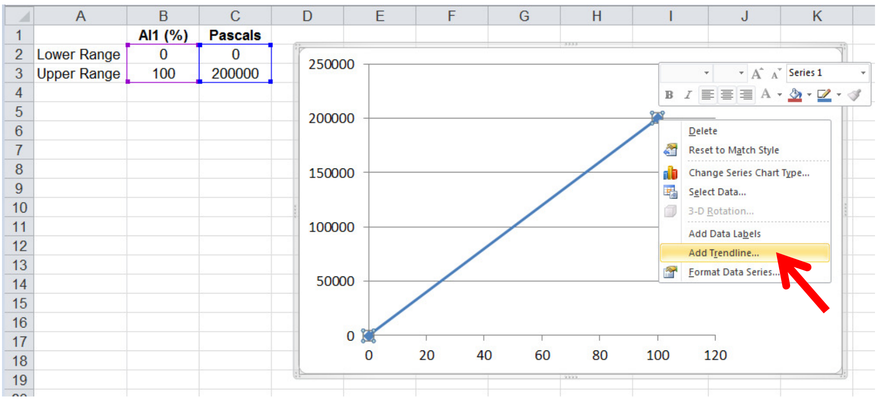
Now click the button as shown below to select the data for the Y-axis.



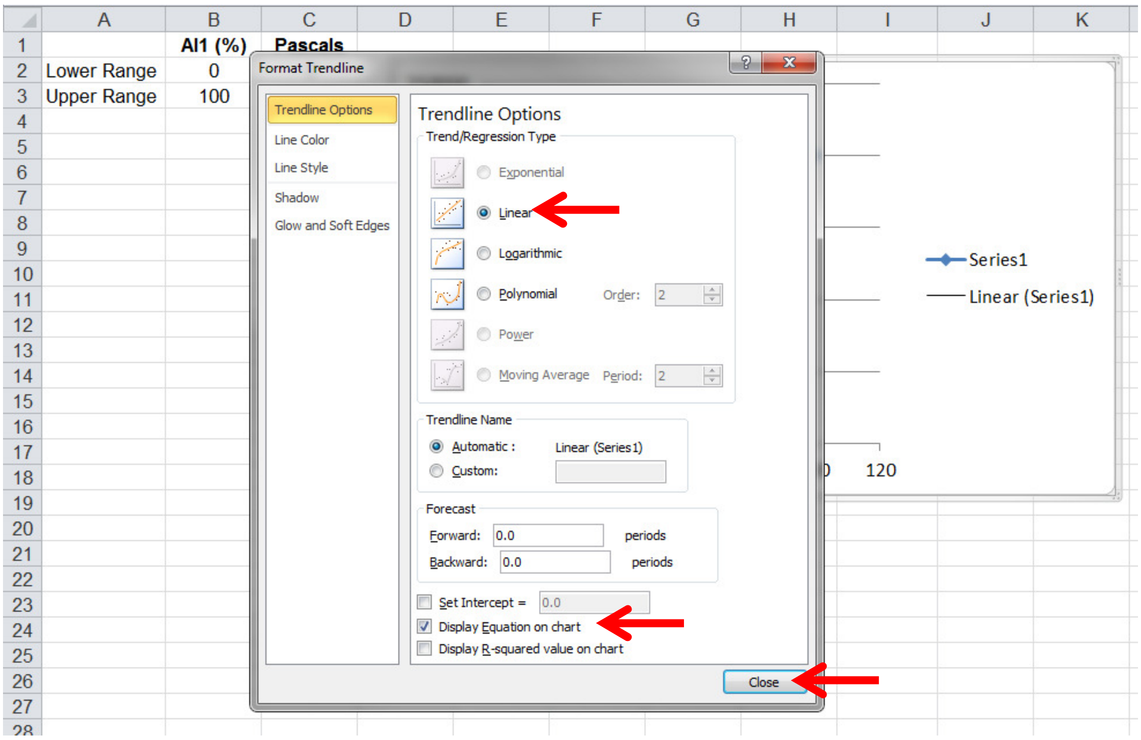
Highlight the 'Pascals' data, and click the button as shown below, then click 'OK' twice to close the next two windows.



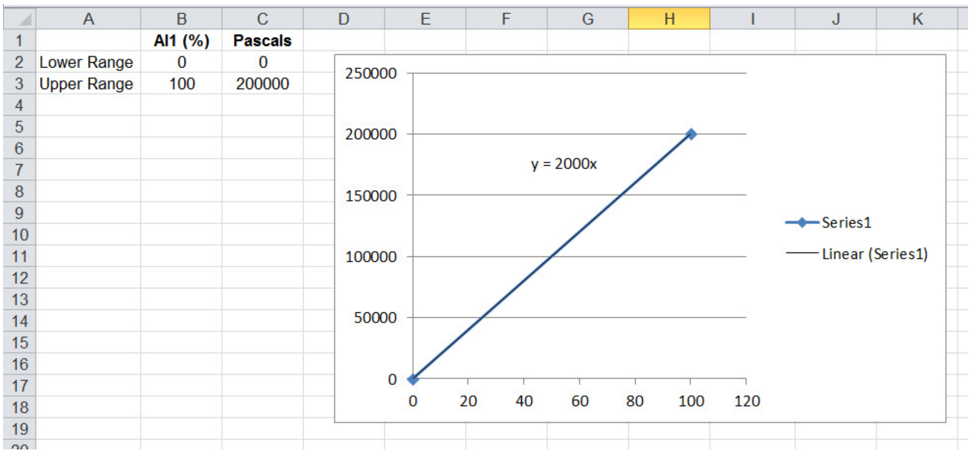
Now a graph of AI1 on the X-axis, verse the pressure value in Pascals on the Y-axis. Now to add a Trendline, right-click on one of the data points on the graph and select ‘Add Trendline…’ as shown below.



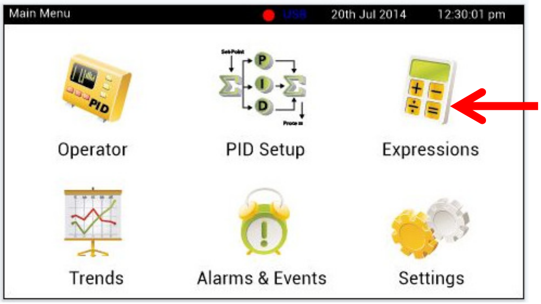
Now the ‘Format Trendline’ window shall appear. Select the ‘Linear’ radio button and the ‘Display Equation on chart’ check box as shown below, and then click the ‘Close’ button.



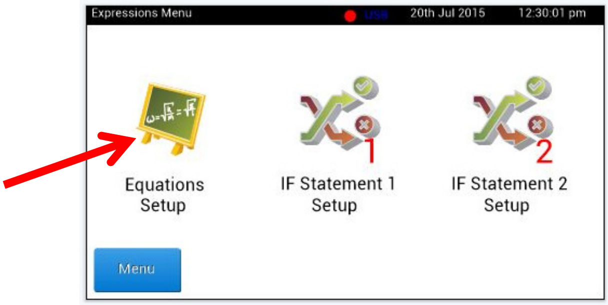
Finally, we have the equation to convert AI1 into Pascals which is y = 2000x.



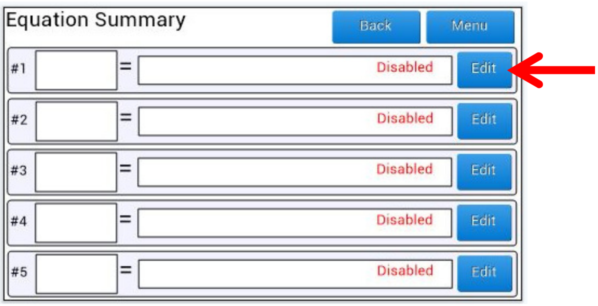
The AP-100 Advanced Process Controller is able to easily execute this equation. To do this, navigate to the 'Equations Summary' page by first pressing the 'Expressions' icon from the 'Main Menu' as shown below.



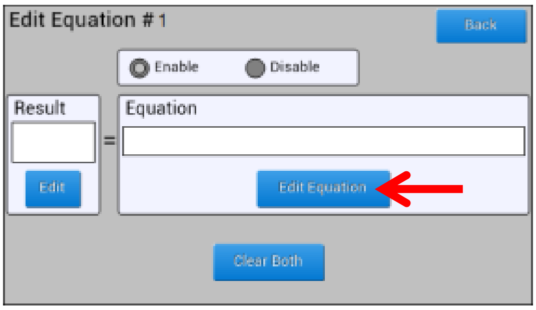
From the 'Expressions Menu' press the 'Equations Setup' icon as shown below.



Below is the 'Equations Summary' page where equations can be entered for execution. Select the next available equation field, in this case, Equation #1 by pressing the corresponding 'Edit' button.

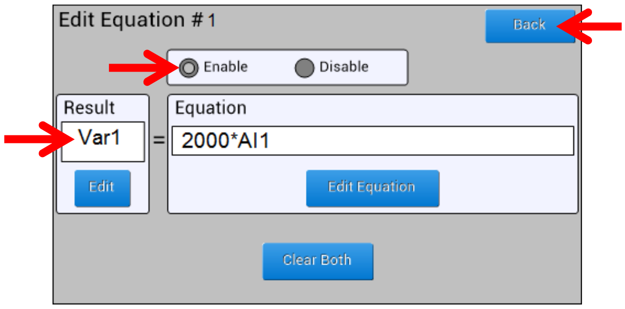


Now the edit equation screen shall appear as shown below. To enter the right-side of the above equation 'y = 2000x' press the 'Edit Equation' button as shown below.

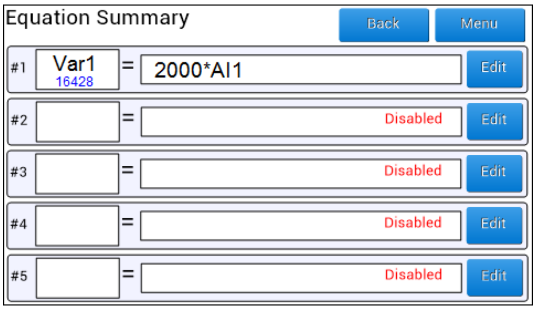


Enter the right-side of equation 'y = 2000x', but substitute the 'x' with the Analogue Input Channel #1 by pressing the 'Var' button as shown below and selecting 'AI1'. Then press the 'OK' button.

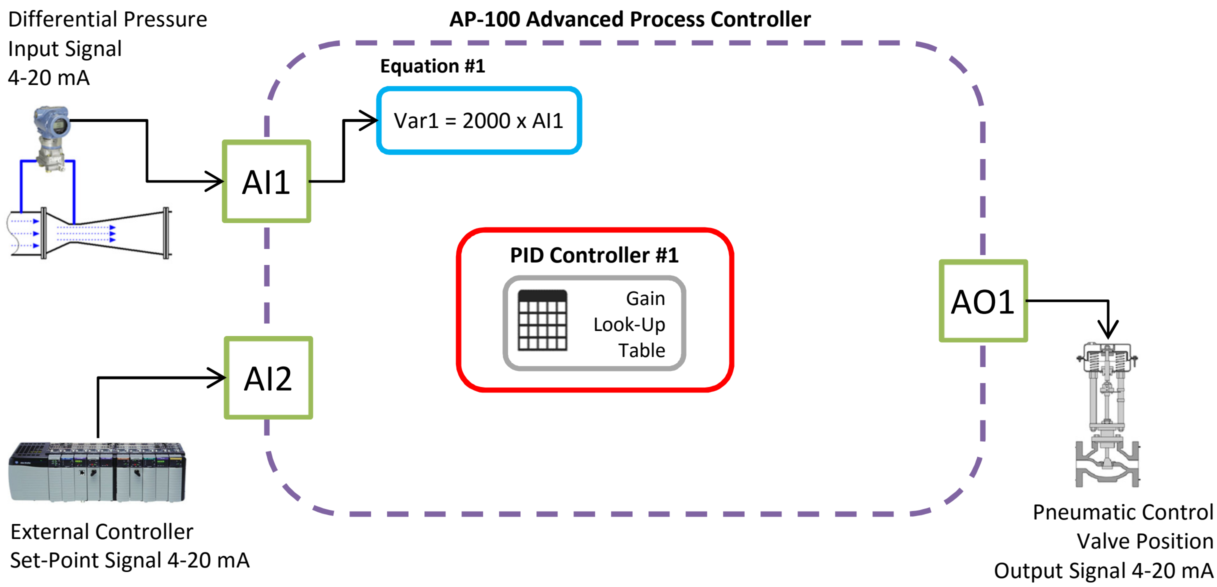
Now that the right-side of the 'y = 2000x' equation has been added, it needs to be 'equalled' to an intermediate variable to storage the result of this equation. To do this press the 'Edit' button as shown below and select the 'Var1' button for Intermediate Variable #1. Now this equation is ready to be enabled, click on the 'Enabled' radio button, then press 'Back' to go back to the 'Equation Summary' page.



Equation #1 has been successfully configured, and shall execute at 100 times per second (100 Hz), the current result of the equations can be seen in the blue text in the results field.



Below visually depicts what has just been created. The Analogue Input CH 1 (AI1) has now been linked to Equation #1, which is assigning its result to Intermediate Variable #1 (Var1).



Now that we have the value of the differential pressure in Pascals from the venturi flow meter, we now need to derive an equation to convert this value into volumetrics flow rate in m^3/secs. This shall be done as follows.

Density of Chlorine can be calculated as:

$$\rho = 1.42\ (1000\ kg/m3) = 1420\ kg/m3$$

The pipe diameter is 0.15 meters and the cross-sectional area is calculated as follows:

$$A_1 = \pi \times \left(\frac{d_1}{2}\right)^2 = \pi \times \left(\frac{0.15}{2}\right)^2 = 0.0177$$

The neck or the venturi flow meter is 0.07 meters and the cross-sectional area is calculated as follows:

$$A_2 = \pi \times \left(\frac{d_2}{2}\right)^2 = \pi \times \left(\frac{0.07}{2}\right)^2 = 0.0038$$

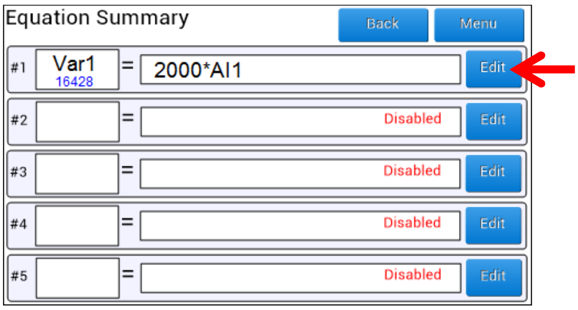
An equation is needed to be derived to convert the differential pressure transmitter's signal into volumetric flow. The above values are substituted into the below equation: (for the following calculation ideal conditions are assumed and the Discharge Coefficient is ignored for simplicity).

$$q = A_2 \sqrt{\left(\frac{2 \times \Delta P}{\rho\left(1-\left(\frac{A_2}{A_1}\right)^2\right)}\right)} = 0.0038 \times \sqrt{\left(\frac{2 \times \Delta P}{1420 \times \left(1-\left(\frac{0.0038}{0.0177}\right)^2\right)}\right)} = 0.0038 \times \sqrt{\left(\frac{2 \times \Delta P}{1354.55}\right)}$$

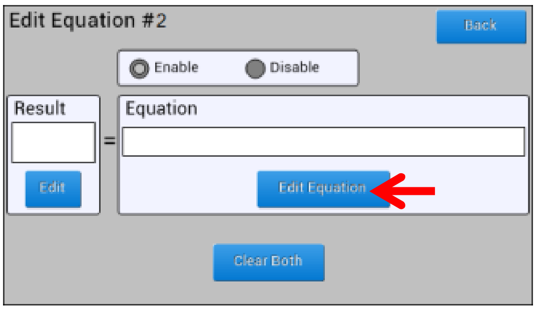
The above equation shall be entered into the AP-100 device as Equation #2. However the ΔP shall be substituted with Var1 from Equation #1. The result of this equation shall be stored into Intermediate Variable #2 (Var2). This equation shall look like the following:

$$Var2 = 0.0038 \times \sqrt{\left(\frac{2 \times Var1}{1354.55}\right)}$$ OR Var2 = 0.0038*Sqrt((2*Var1)/1354.55))

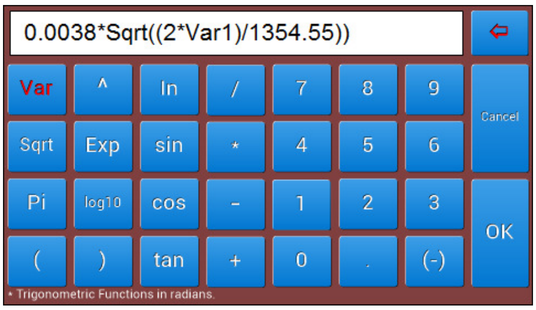
Similar to before, press the corresponding ‘Edit’ button for Equation #2, as shown below.



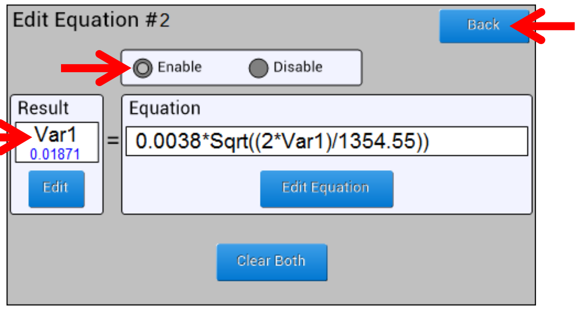
Then press the ‘Edit Equation’ button, as shown below.



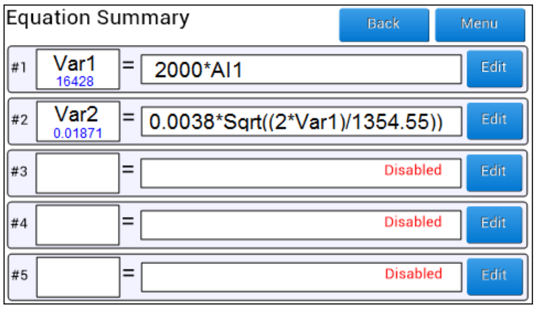
Now enter the above equations as shown below, then press ‘OK’.



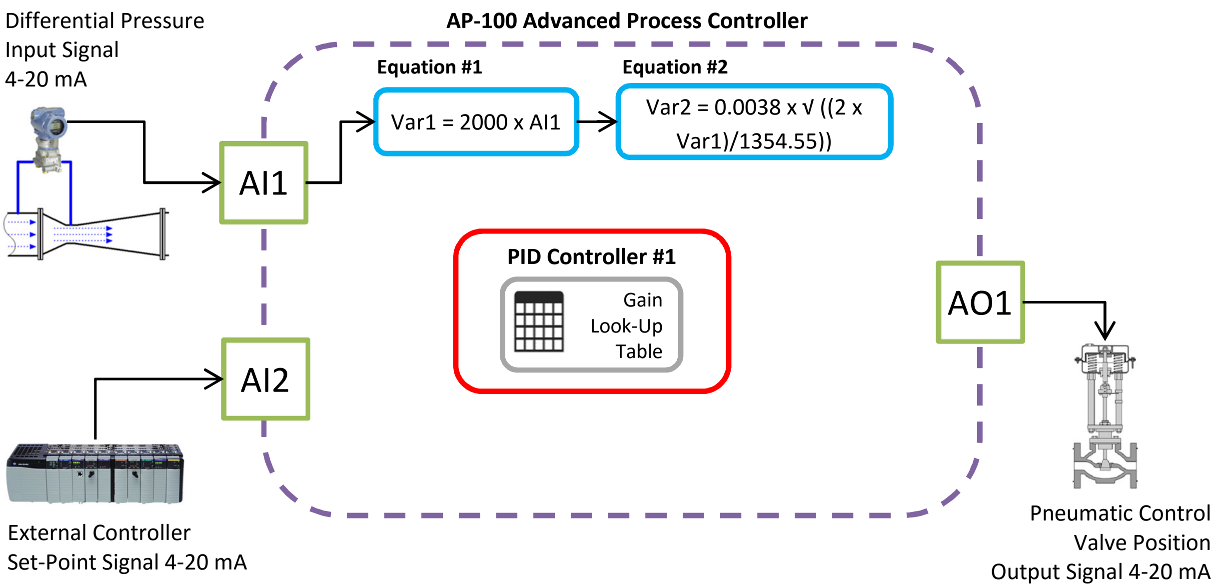
Press the ‘Edit’ button in the results field and then select ‘Var2’ to assign the result of Equation #2 to Intermediate Variable #2. Press the ‘Enable’ radio button to enable Equation #2, then press the ‘Back’ button to go back to the ‘Equation Summary’ page.



Now Equation #2 is enabled and executing. The current result of Equation #2 (Var2) can be seen in blue text in the Results field. The intermediate variable Var2 is the volumetric flow rate of Chlorine through the venturi flow meter in m^3/sec. Var2 can be Trended and recorded to view and save the history of this signal, see the section on Trending Data for more information.



Below visually depicts what has just been created. The result of Equation #1 (Var1) has been include into Equation #2. The result of Equation #2 has been assigned it Intermediate Variable #2 (Var2).



Now that we have the flow rate of chlorine, we need to connect this signal to the PID Controller #1. But first we need to re-range Var2, as the range of the PID Controller #1 is 0.00% to 100.00% and the range of Var2 can be calculated as follows:

Lower range at 0 Pascals (0 Bar):

$$Flow_{Lower} = 0.0038 \times \sqrt{\left(\frac{2 \times \Delta P}{1354.55}\right)}$$

$$= 0.0038 \times \sqrt{\left(\frac{2 \times 0}{1354.55}\right)}$$

$$= 0$$

Upper range at 200000 Pascals (2 Bar):

$$Flow_{Lower} = 0.0038 \times \sqrt{\left(\frac{2 \times \Delta P}{1354.55}\right)}$$

$$= 0.0038 \times \sqrt{\left(\frac{2 \times 200000}{1354.55}\right)}$$

$$= 0.0653$$

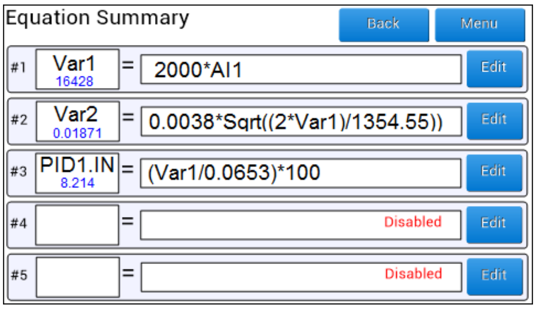
An Equation #3 needs to be derived to re-scale the Var2 of Equation #2 to be the input of PID Controller #1, as follows:

$$PID1.IN = \left(\frac{Var2}{0.0653}\right) * 100$$

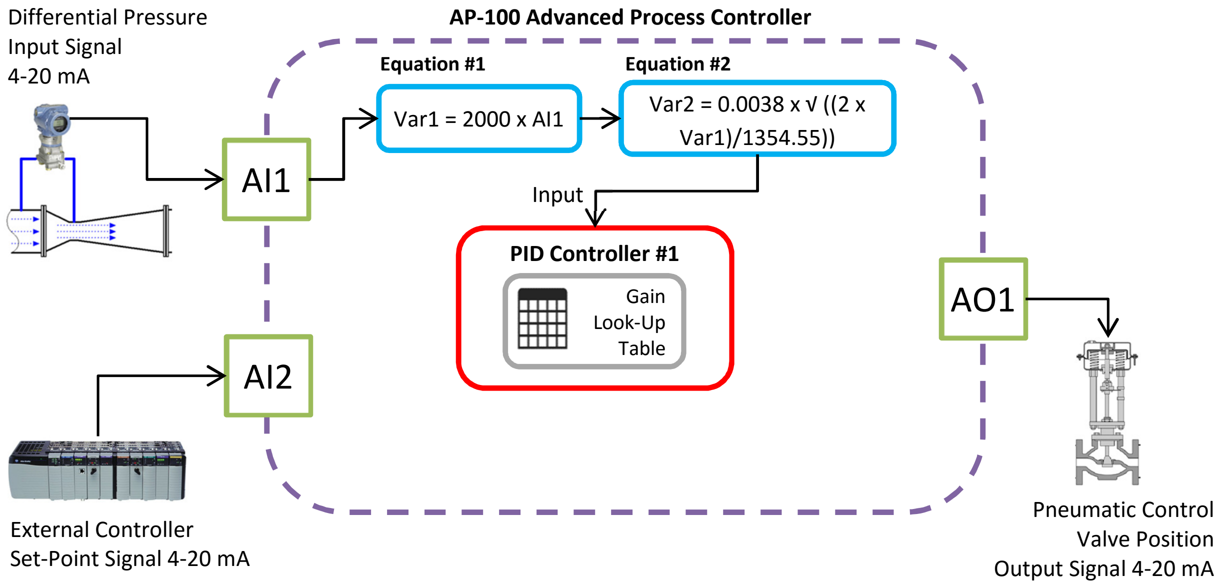
OR

PID1.IN = (Var1/0.0653)*100

Follow the same steps taken for Equations #1 and #2 to implement the above for Equation #3 as shown below.



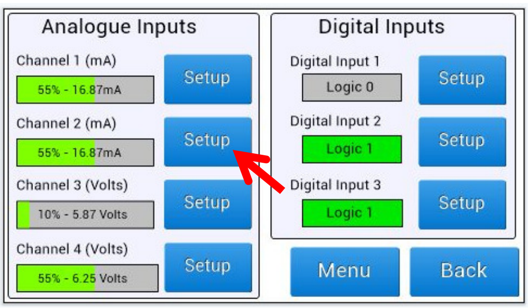
Below visually depicts what has just been created. The result of Equation #3 (Var2) has been included into Equation #3. The result of Equation #3 has been assigned to the Input of PID Controller #1 (PID1.IN).



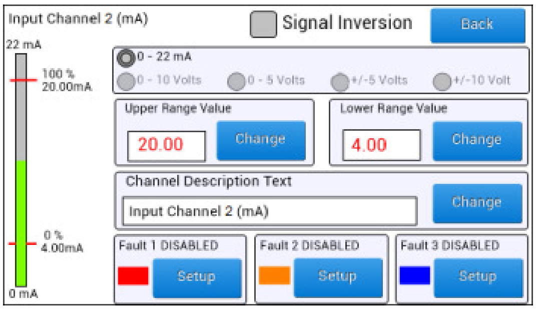
13.2. Setup Set-Point Signal

The Set-Point for PID Controllers in the AP-100 Advanced Process Controller can be set by the user in the 'Operator' page (see Section 'Operator' Screen). However, in this example the Set-Point signal (4-20mA) for PID Controller #1 shall come from an external device such as a PLC or remote HMI. In this configuration the complex equations and PID Control algorithms can be computed in the AP-100 to simplify the overall design of the system.

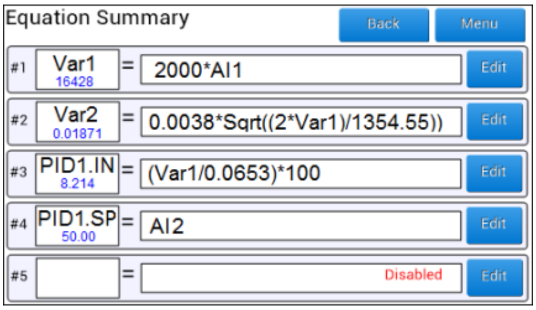
For the AP-100 Device to receive the 4-20mA Set-Point signal the Analogue Input Channel #2 shall need to be configured. As before, navigate to the 'Inputs Summary' page and press the corresponding 'Change' button for Analogue Input Channel #2.



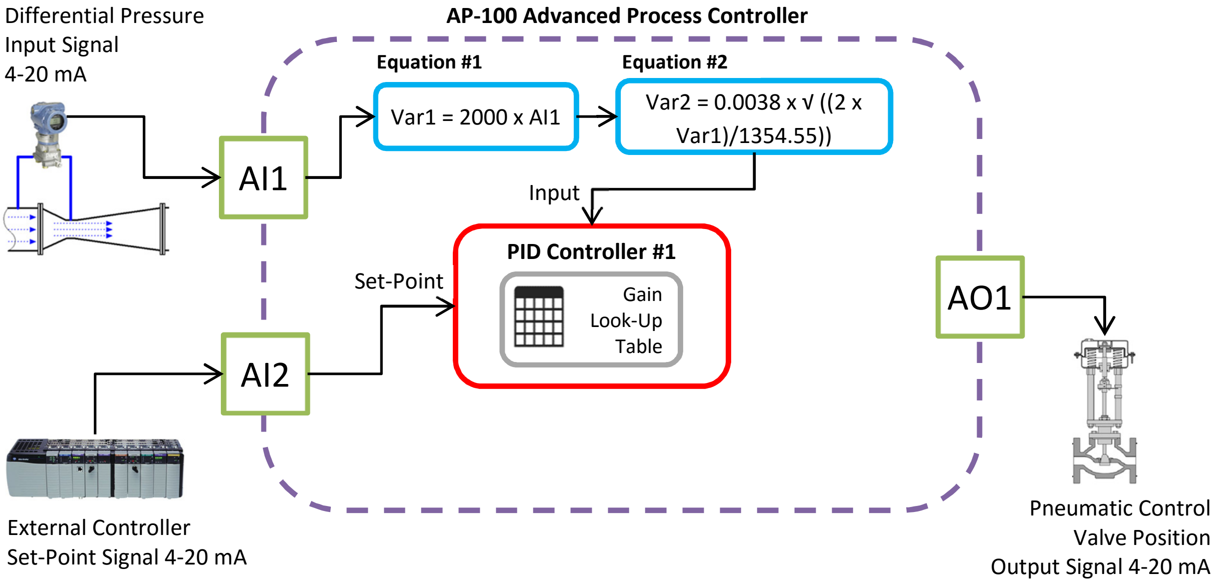
As shown below, ensure that the Upper and Lower range limits are 20.00 and 4.00 respectively. If there differ, press the corresponding 'Change' buttons and enter the correct value. Ensure that the 'Signal Inversion' check box is unchecked. The user may wish to change the 'Channel Description Text'.



Now that the input signal for the Set-Point has been configure, it needs to be connected to PID Controller #1. This is done in the 'Equations Summary' page. Enter the equation below into Equation #4 in the similar way as the previous equations.

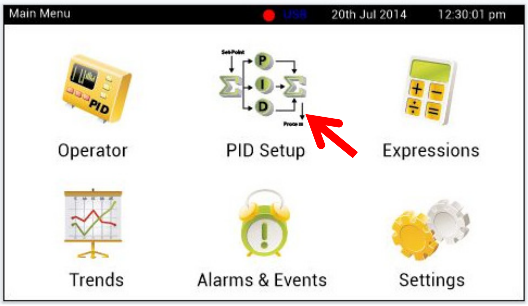


Below visually depicts what has just been created. An external controller is providing the Set-Point value through Analogue Input Channel #2 (AI2). The Equation #4 is configured to connect the value at Analogue Input Channel #2 (AI2) as the Set-Point for PID Controller #1.

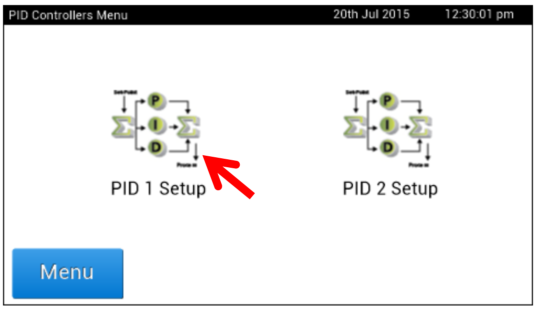


13.3. Setup PID Controller #1

To navigate to PID Controller #1, press the 'PID Setup' icon from the Main Menu. This shall display the PID Controller sub-menu.



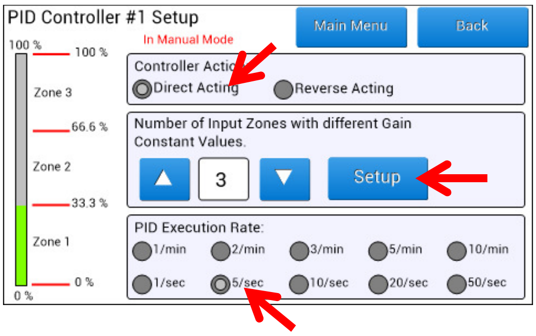
Then press the 'PID Controller Setup' icon, as shown below.



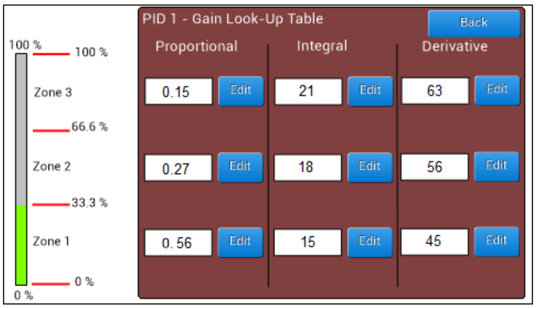
The first step is to determine whether this PID Controller is to be setup as 'Direct Acting' or 'Reverse Acting'. If the chlorine flows through the venturi meter decreases below the Set-Point, the PID Controller will try to increase the flow rate by opening the Control Valve further. Therefore, a positive change of PID Controller output shall cause a positive change in the process measurement, being the Flow-Rate. Conversely, a negative change in of PID Controller output shall cause a negative change in the process measurement. Therefore, this PID Controller shall be setup as 'Direct Action', press the associated radio button as shown below.

As flow control is a fast process, the 'PID Execution Rate' shall be set for 5 execution cycles per second. Therefore, select the '5/sec' radio button as shown below.

For optimal control, this PID Controller shall be setup to have 3 input Zones. This means that the Input signal range shall be divided up into 3 Zones and there shall be a different set of PID gain values for each of these zones. Press the associated up arrow button, as shown below, to create 3 Input Zones. Then press the associated 'Setup' button to display the PID gain values.

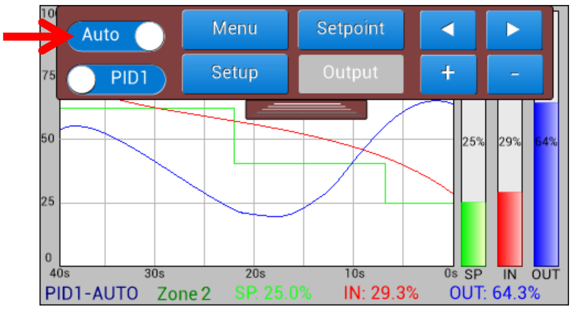


From using standard open-loop step response PID tuning practises the following PID gain values were obtains and entered in as shown below.



To start PID Controller #1 executing, it must be put into Automatic Mode. To do this press the 'Operator' icon from the Main Menu, as shown below.

From the 'Drop-Down Tab Menu', set the top left toggle switch to 'Auto' mode as shown below. PID Controller #1 shall start executing and accepting its Set-Point values from the external controller.



13.4. Setup Output Signal

The output from PID Controller #1 shall be linked to Analogue Output Channel #1 which is connected to a pneumatic valve positioner with a 4-20mA signal. The pneumatic valve in this example is a 1" Fisher HPAS Micro-Form Plug valve with a port diameter of 12.7mm. This valve has an Equal-Percent profile to match the profile of an upstream pump curve. This means, the control valve has a valve plug shaped so that each increment in valve lift increases the flow-rate by a certain percentage of the previous flow. The relationship between valve lift and orifice size (and therefore flow-rate) is not linear but logarithmic.

Therefore, if the pneumatic valve is sent a signal of 40%, then the flow-rate through the control valve would not be 40%, but instead would be approximately 14%.

An equation needs to be derived to linearize the Analogue Output Channel #1 signals so that if the output from PID Controller #1 is 40%, then the flow-rate through the valve shall be 40%. To derive this equation we shall extract the C_v values verse valve stem travel from the control valve's datasheet, as shown below.

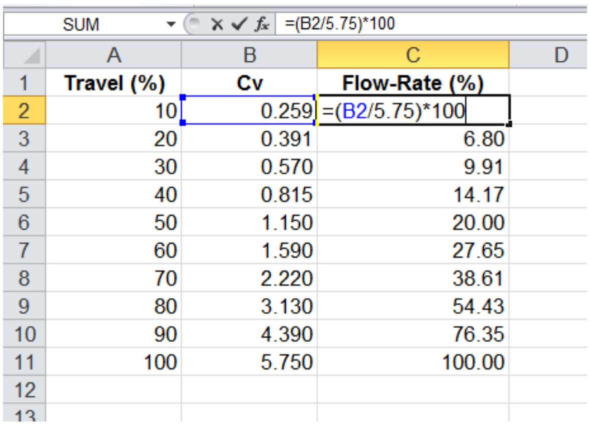
HPAS, Micro-Form, Flow Up — Equal Percentage Characteristic

Valve Size, NPS	Port Diameter mm	Port Diameter Inches	Maximum Travel mm	Maximum Travel Inches	Flow Coefficient	10	20	30	40	50	60	70	80	90	100	F_L(1)
	6.4	0.25	19	0.75	C_v	0.089	0.123	0.175	0.242	0.331	0.456	0.643	0.910	1.24	1.58	0.93
					K_v	*0.077*	*0.106*	*0.151*	*0.209*	*0.286*	*0.394*	*0.556*	*0.787*	*1.07*	*1.37*	---
					X_T	0.658	0.666	0.611	0.603	0.613	0.613	0.588	0.578	0.616	0.651	---
1	12.7	0.5	19	0.75	C_v	0.259	0.391	0.570	0.815	1.15	1.59	2.22	3.13	4.39	5.75	0.98
					K_v	*0.224*	*0.338*	*0.493*	*0.705*	*0.995*	*1.38*	*1.92*	*2.71*	*3.80*	*4.97*	---
					X_T	0.633	0.606	0.576	0.572	0.576	0.593	0.604	0.624	0.662	0.691	---
					C	0.464	0.695	0.987	1.43	2.12	3.16	4.71	6.89	9.56	11.4	0.97

As before, we shall use MS Excel to derive this equation by first plotting the above data onto a graph and then adding a trendline. Enter the above data into an empty spreadsheet as shown below.

	A	B	C	D
1	Travel (%)	Cv	Flow-Rate (%)	
2	10	0.259		
3	20	0.391		
4	30	0.570		
5	40	0.815		
6	50	1.150		
7	60	1.590		
8	70	2.220		
9	80	3.130		
10	90	4.390		
11	100	5.750		
12				

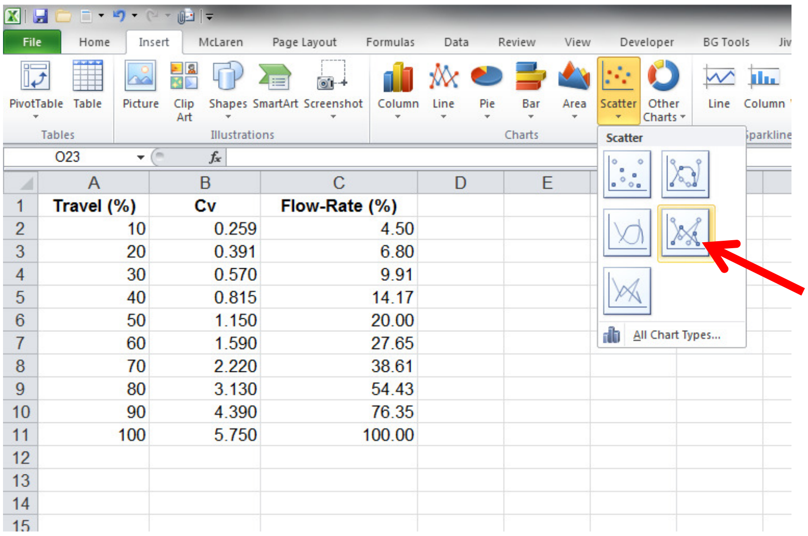
The control valve's datasheet gives the percent of valve stem travel verses C_v values. These C_v values needs to be converted into Flow-Rate in percent (%). To do this we divide each of the C_v values by the maximum C_v value and then multiply by 100. Enter the equation "=(B2/5.75)*100" into cell C3, then highlight and drag this cell down for the rest of the cells.



SUM =(B2/5.75)*100

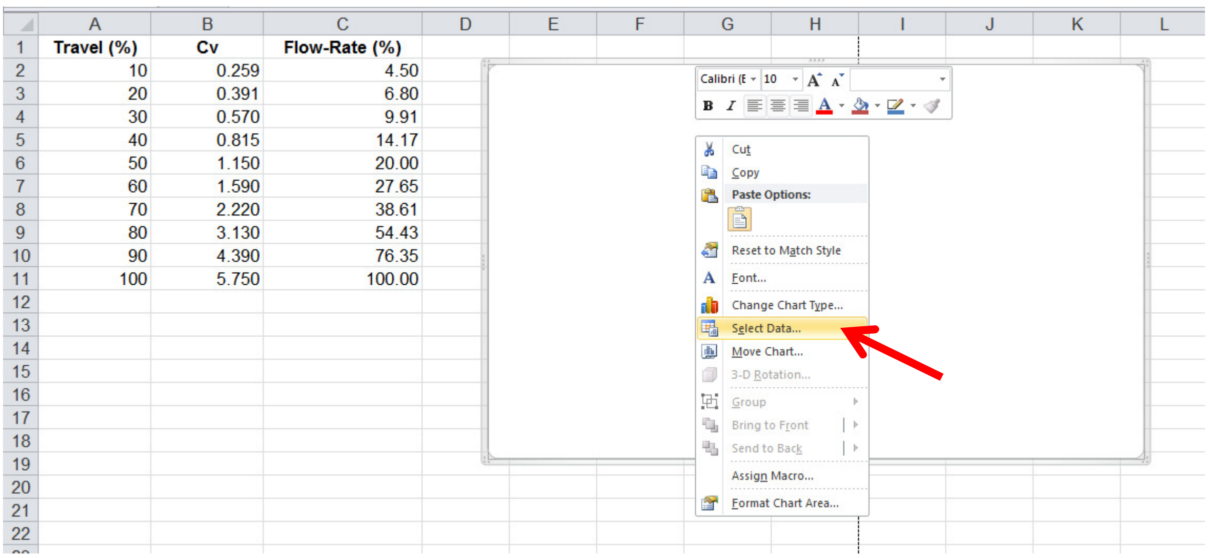
	A	B	C
1	Travel (%)	Cv	Flow-Rate (%)
2	10	0.259	=(B2/5.75)*100
3	20	0.391	6.80
4	30	0.570	9.91
5	40	0.815	14.17
6	50	1.150	20.00
7	60	1.590	27.65
8	70	2.220	38.61
9	80	3.130	54.43
10	90	4.390	76.35
11	100	5.750	100.00

Then without highlighting any data, select from the top toolbar menu Insert > Charts > Scatter Chart.



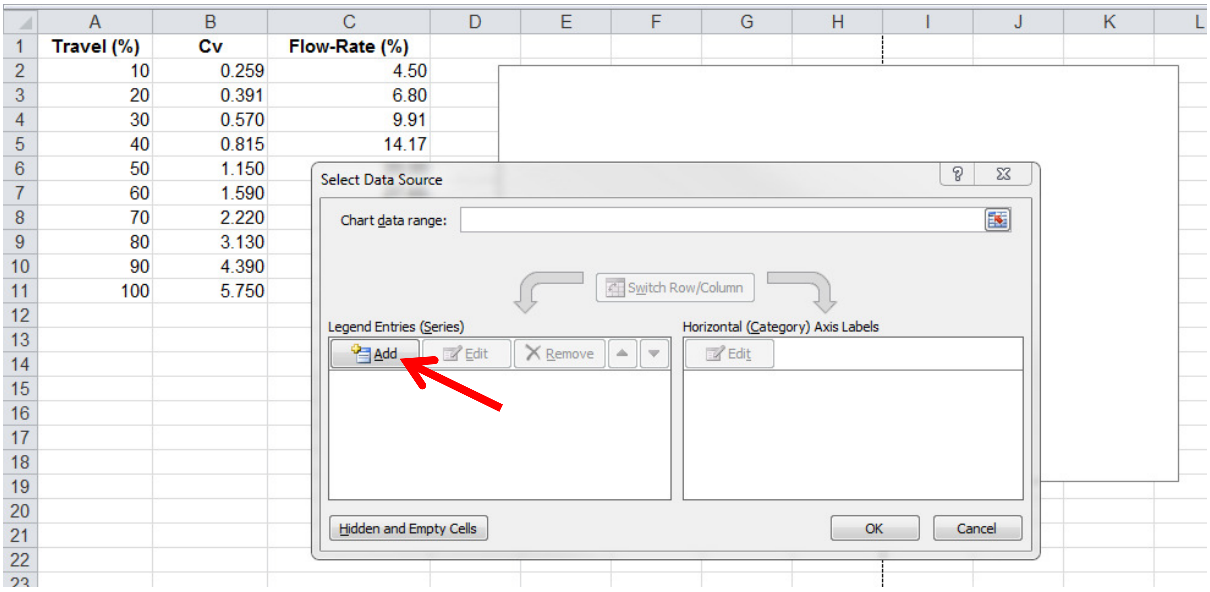
	A	B	C
1	Travel (%)	Cv	Flow-Rate (%)
2	10	0.259	4.50
3	20	0.391	6.80
4	30	0.570	9.91
5	40	0.815	14.17
6	50	1.150	20.00
7	60	1.590	27.65
8	70	2.220	38.61
9	80	3.130	54.43
10	90	4.390	76.35
11	100	5.750	100.00

This shall display an empty graph with no data, as shown below. Right-Click on the empty graph area and chose 'Select Data…'.

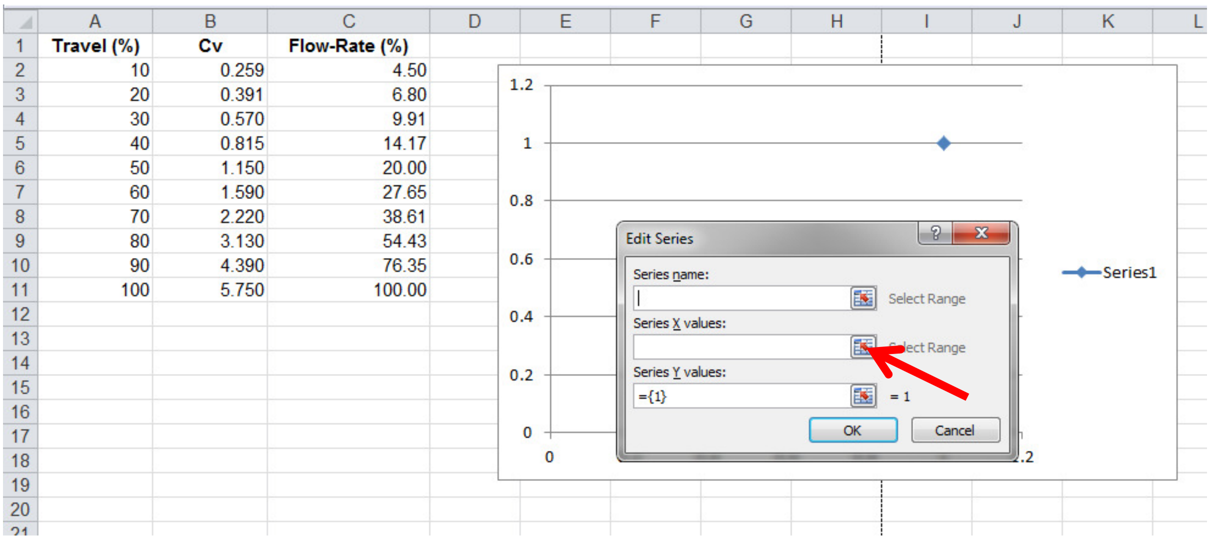


	A	B	C
1	Travel (%)	Cv	Flow-Rate (%)
2	10	0.259	4.50
3	20	0.391	6.80
4	30	0.570	9.91
5	40	0.815	14.17
6	50	1.150	20.00
7	60	1.590	27.65
8	70	2.220	38.61
9	80	3.130	54.43
10	90	4.390	76.35
11	100	5.750	100.00

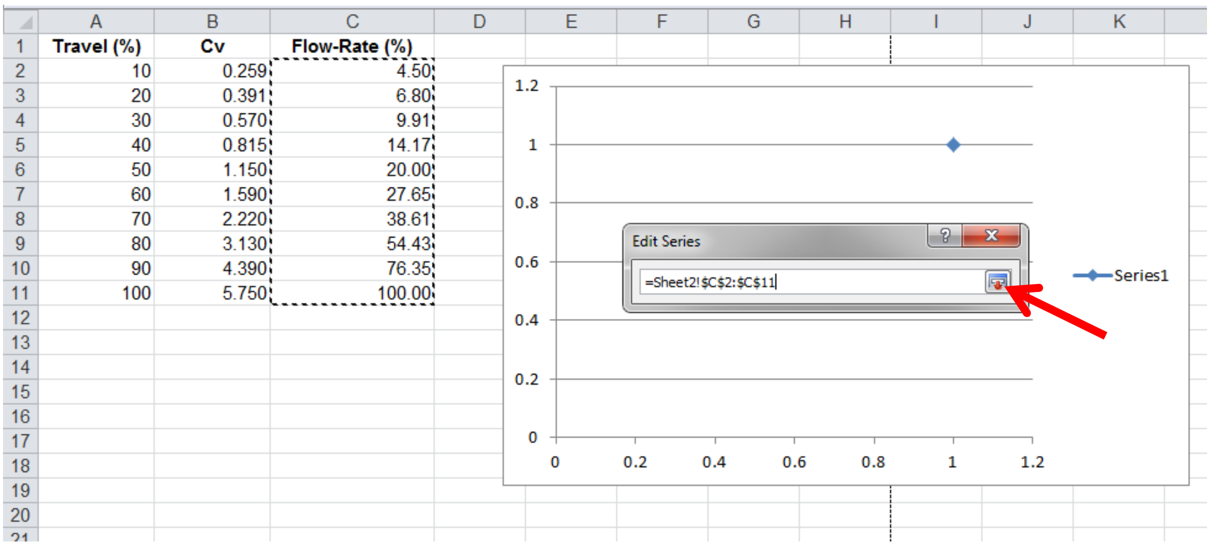
This shall display the 'Select Source Data' window. Click the 'Add' button as shown below.



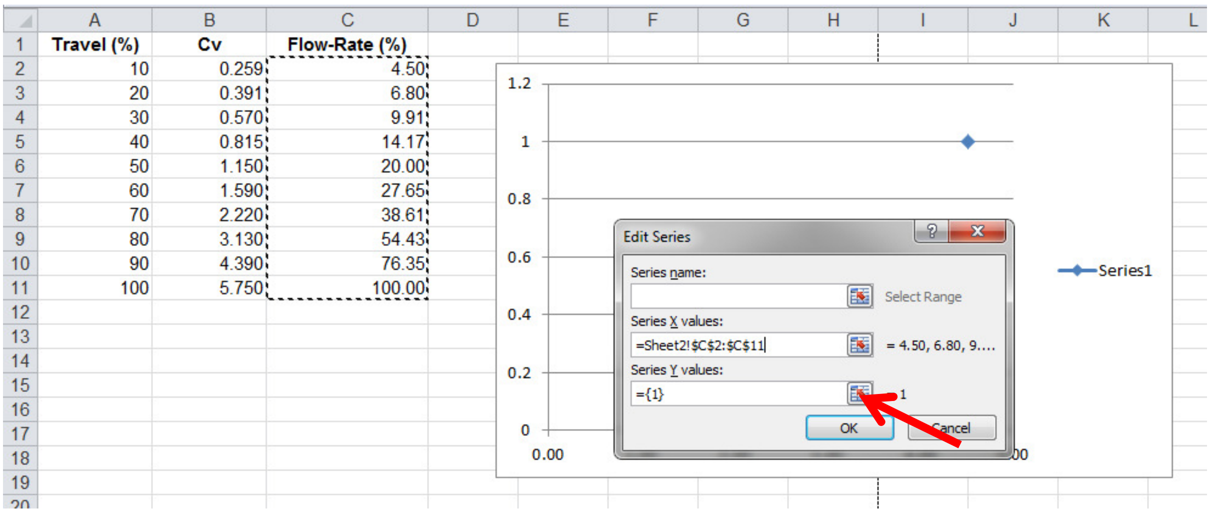
A new widow shall appear, Click on the button as shown below to add the data for the X-axis of the graph.



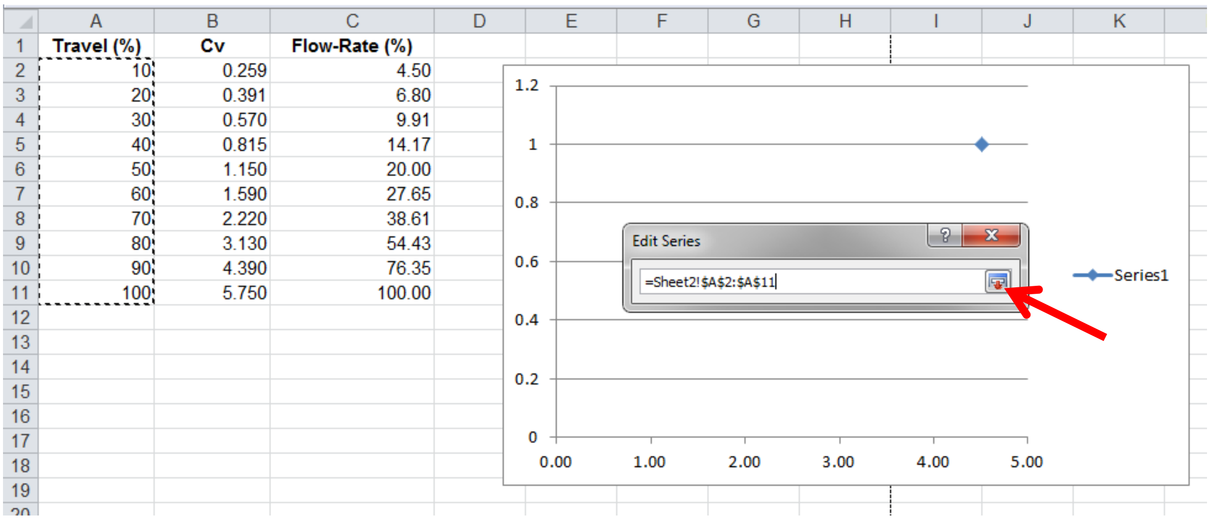
Highlight the ‘Flow-Rate (%)’ data, then click the button as shown below.



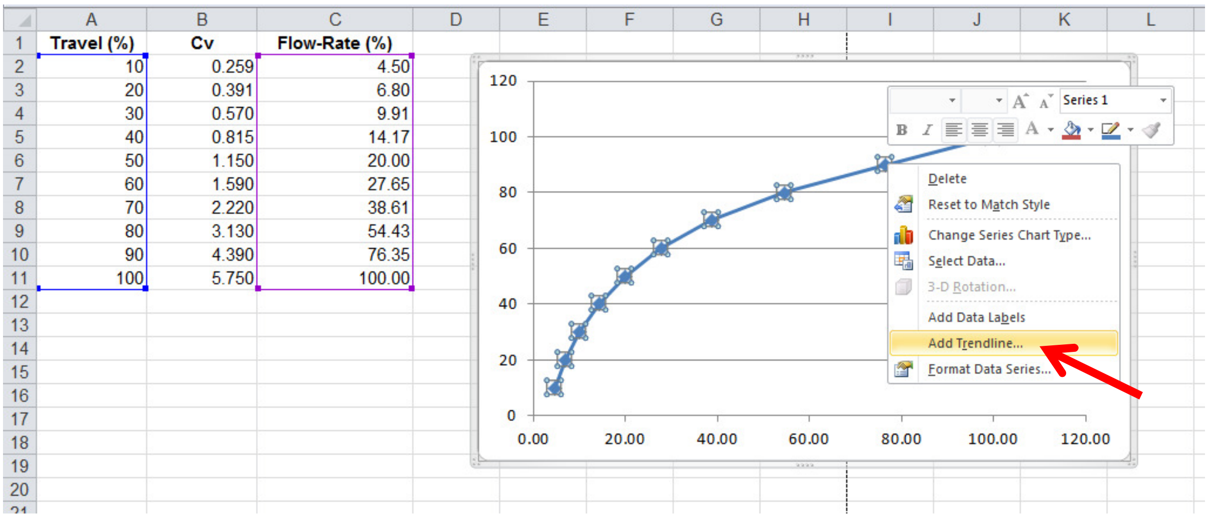
Now click the button as shown below to select the data for the Y-axis.



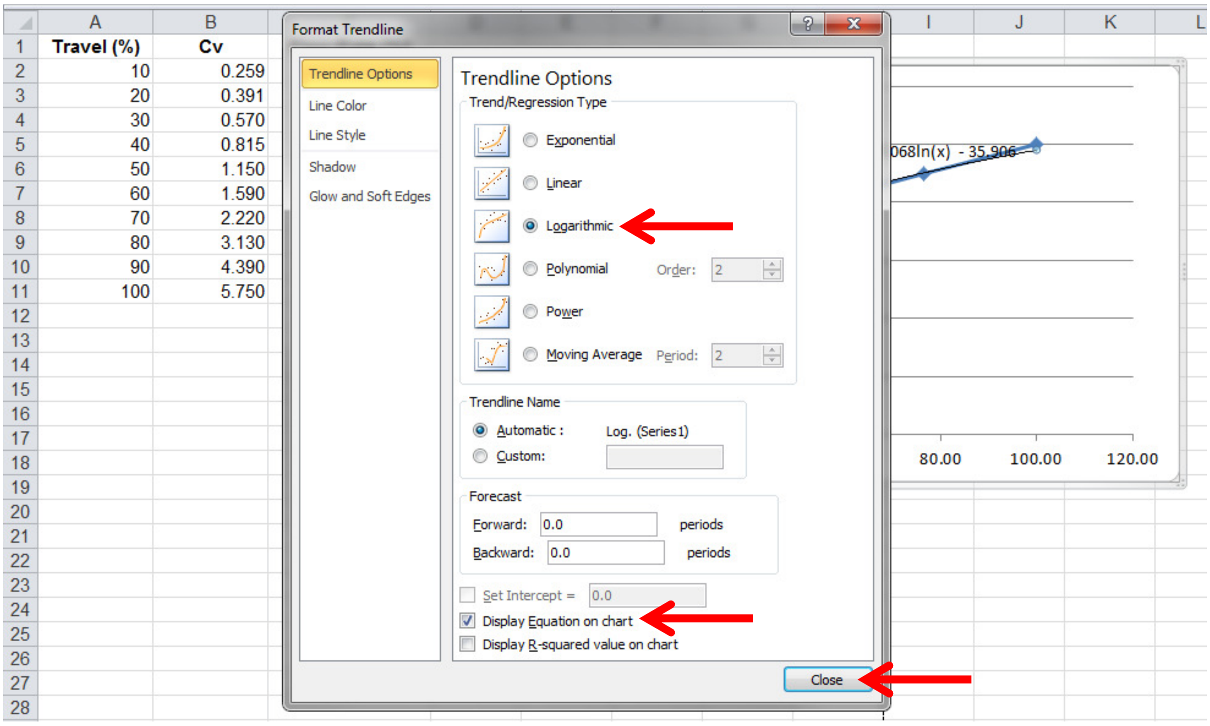
Highlight the 'Travel (%)' data, and click the button as shown below, then click 'OK' twice to close the next two windows.



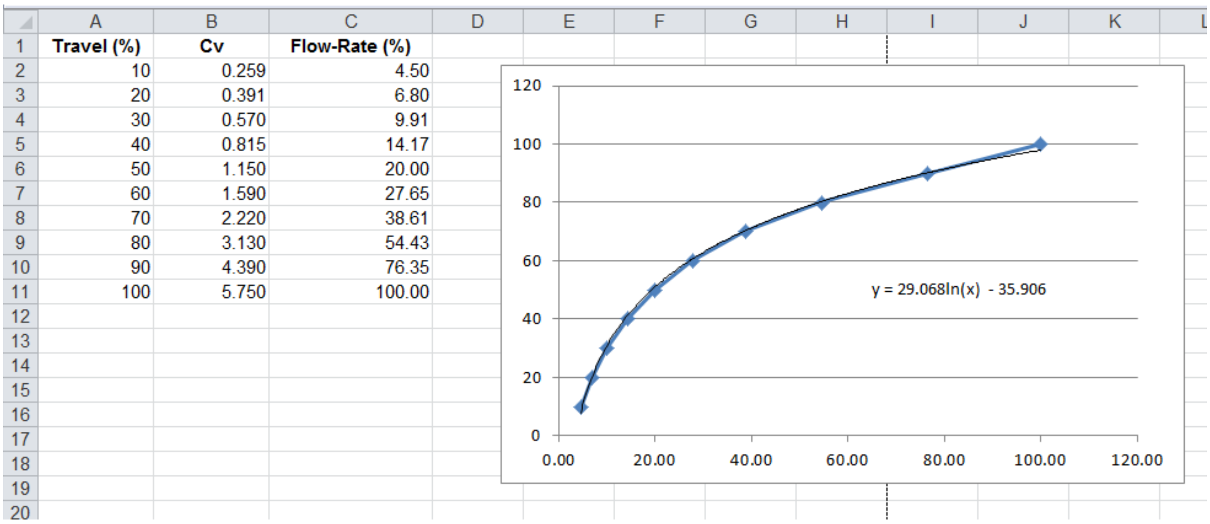
Now a graph shall display the Control Valve's Flow-Rate (%) on the X-axis, verse the Control Valves stem's travel movement (%) on the Y-axis. Now to add a Trendline, right-click on one of the data points on the graph and select 'Add Trendline…' as shown below.



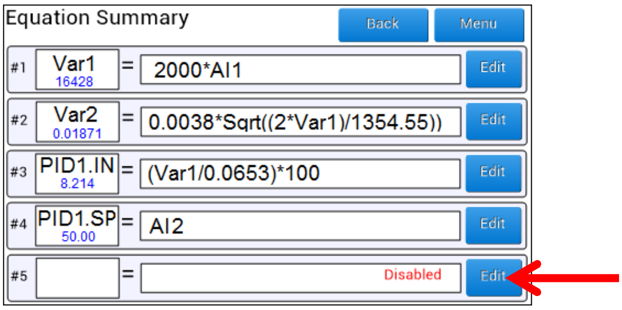
Now the ‘Format Trendline’ window shall appear. Select the ‘Logarithmic’ radio button and the ‘Display Equation on chart’ check box as shown below, and then click the ‘Close’ button.



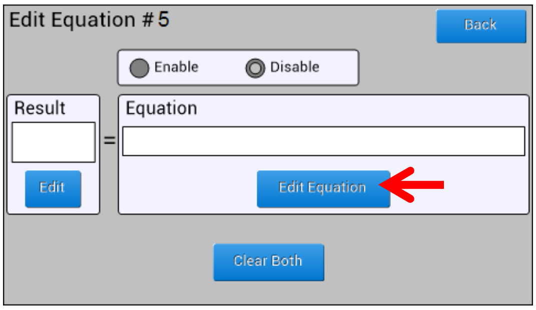
Finally, we have the equation to convert the Control Valve’s Flow-Rate (%) to the Control Valves stem’s travel movement (%), which is y = 29.068 × In(x) – 35.906.



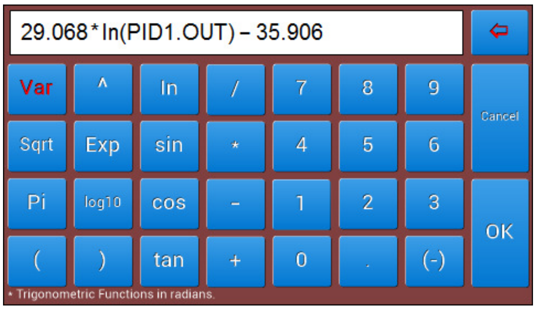
Enter the above equation into the AP-100 similar as before, by pressing the corresponding ‘Edit’ button for Equation #5, on the ‘Equations Summary Page’, as shown below.



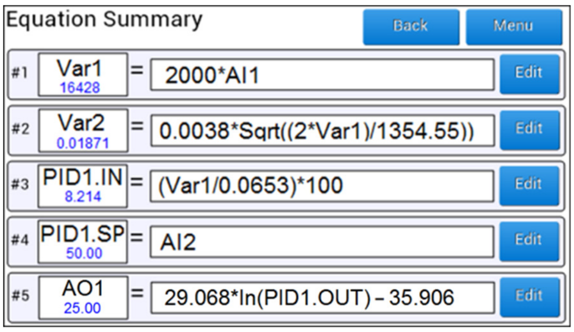
Then press the 'Edit Equation' button, as shown below.



Now enter the above equations as shown below, then press 'OK'. Be sure to substitute the 'x' for 'PID1.OUT'. The latter is the Output signal from the PID Controller #1.

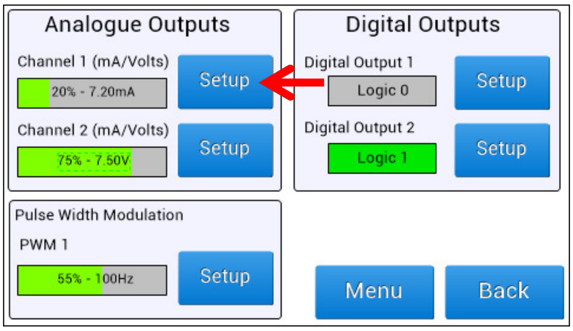


Press the 'Edit' button in the results field and then select 'AO1' to assign the result of Equation #5 to Analogue Output Channel #1. Press the 'Enable' radio button to enable Equation #5, then press the 'Back' button to go back to the 'Equation Summary' page.

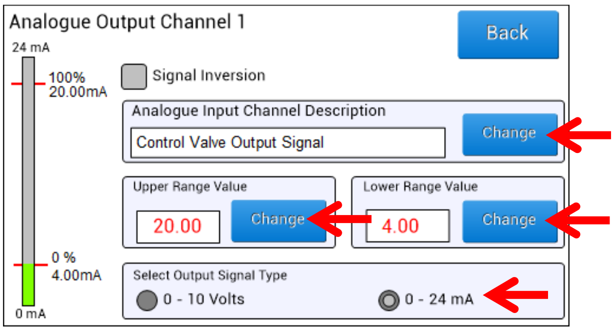


Now the Output signal from PID Controller #1 is assigned to Analogue Output Channel #1 through an equation the linearizes the Control Valve's stem travel (%) verse Flow-Rate (%) through the valve.

For the AP-100 Device to output the 4-20mA Control Valve signal the Analogue Output Channel #1 shall need to be configured. As before, navigate to the 'Outputs Summary' page and press the corresponding 'Setup' button for Analogue Output Channel #1.

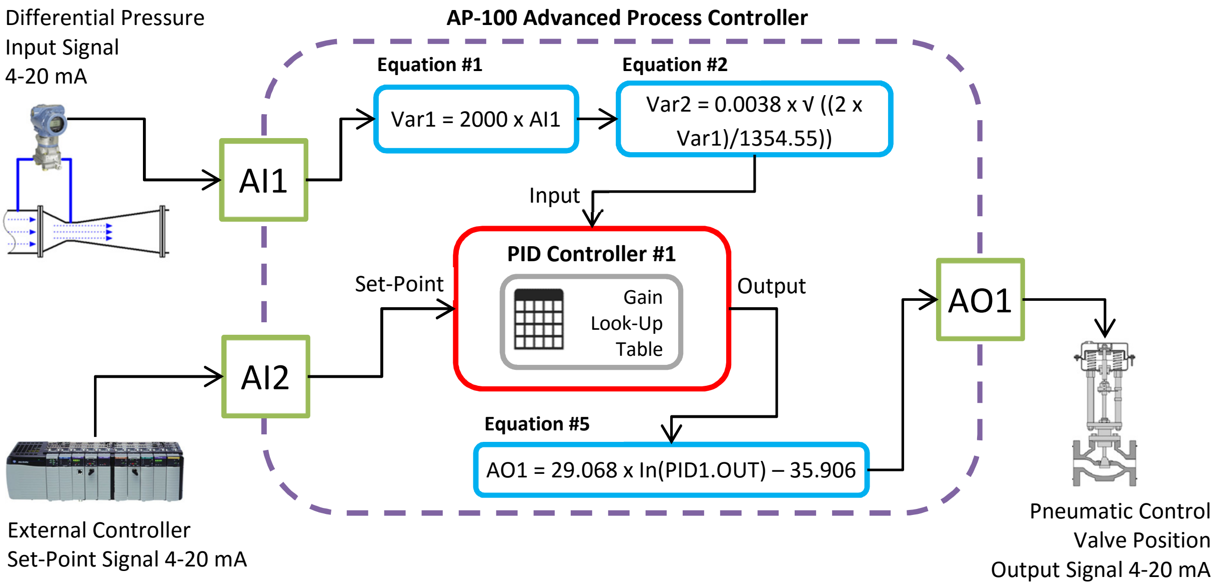


This shall display the Setup page for the Analogue Output Channel #1, as shown below. Press the '0 – 24 mA' radio button at the bottom right to have this channel set to current mode. Change the Upper and Lower ranges to 20 mA and 4 mA respectively. Change the description text to 'Control Value Output Signal', then press the 'Back' button to complete setup.



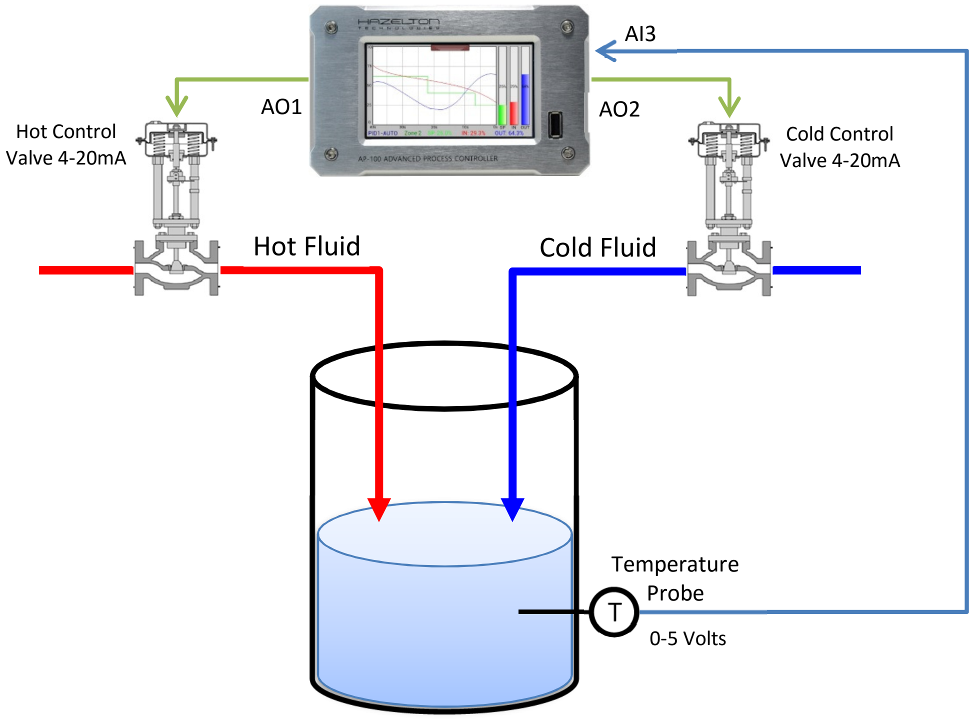
13.5. Conclusion

The AP-100 Advanced Process Controller has now been setup as a PID flow controller for a liquid Chlorine line. The flow rate is to be measured with a venturi flow meter and differential pressure transmitter, which shall be a 4-20mA signal input into the AP-100 device. This input signal shall then be the input into the internal PID Controller to the AP-100 device. The PID Controller's Output shall drive a 4-20mA signal to a pneumatic control valve. The AP-100 device shall have a second 4-20mA input signal from an external PLC that shall be the Set-Point signal for the PID controller.

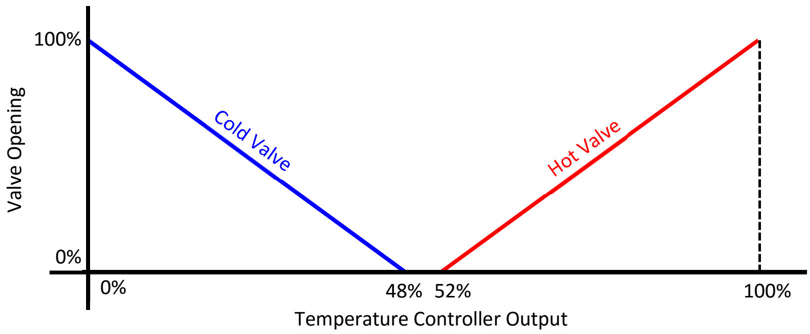


14. CASE STUDY - SPLIT RANGE TEMPERATURE PID CONTROLLER

In this case study the AP-100 Advances Process Controller is being used to control the temperature of fluid within a tank with its internal PID Controller, as shown below. The AP-100 device reads the fluid temperature from an RTD temperature probe that outputs a 0 to 5 Volt signal for 0 to 200˚C respectively. The AP-100 shall control the fluid temperature by manipulating two control valves. One control valve is on a hot fluid inlet line and the other is on a cold fluid inlet line into the tank. Both control valves receive a 4 to 20 mA signal for 0% to 100% open respectively.

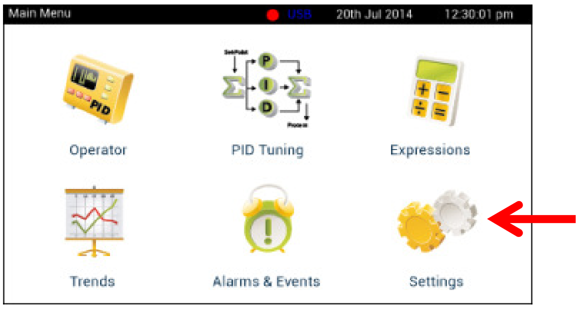


The 0% to 100% range of the Output of the PID Controller is split in two between the two valves. If the controller output is between 0% and 48%, the cold fluid valve is operated. This valve is fully open when the controller output is 0% and fully closed when the controller output is 48%. If the controller output is between 52% and 100%, the hot fluid valve will be operated. At 52% controller output, the hot fluid valve starts to open and it is fully open at 100%. There is a dead-band between 48% and 52% of controller output where both valves remain closed. The dead-band is to prevent valve seat ware-out from the controller constantly switching between the two valves.



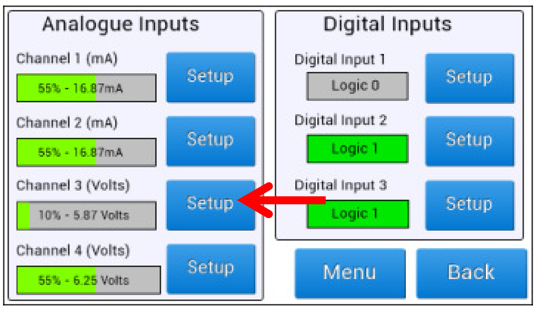
14.1. Analogue Input Signal Setup

The AP-100 device reads the temperature of the fluid within the tank from an RTD temperature probe that outputs a 0 to 5 volt signal for 0 to 200˚C respectively. This voltage signal is read into the AP-100 device through Analogue Input Channel #3. The first step is to configure the Analogue Input Channel #3 to read this signal. To navigate to the Analogue Input Channel #3 setup screen press the 'Settings' icon on the Main Menu as shown below.

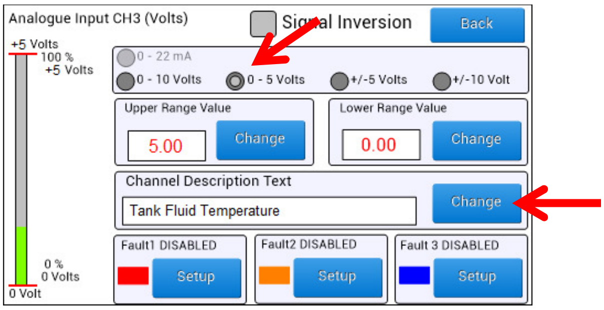


Press the 'Input Channels Setup' icon as shown below.

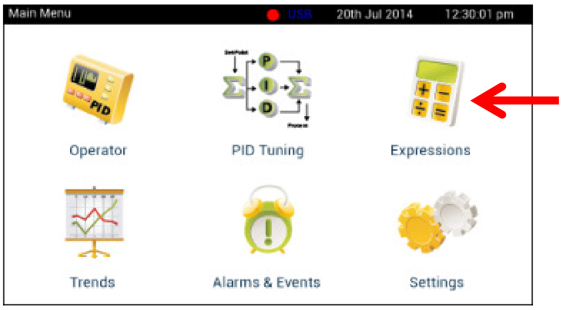
Press the corresponding 'Setup' button for Analogue Input Channel #3.



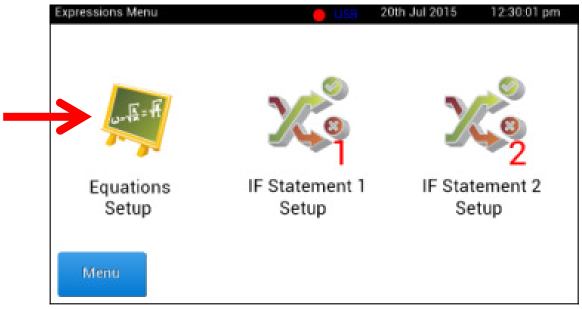
Shown below is the Analogue Input Channel #3 setup screen. Press the '0-5 Volts' radio button to change the minimum and maximum ranges. Then press the corresponding 'Change' button for the 'Channel Description Text' and change the description to “Tank Fluid Temperature”. Press the ‘Back’ button and navigate to the Main Menu when finished.



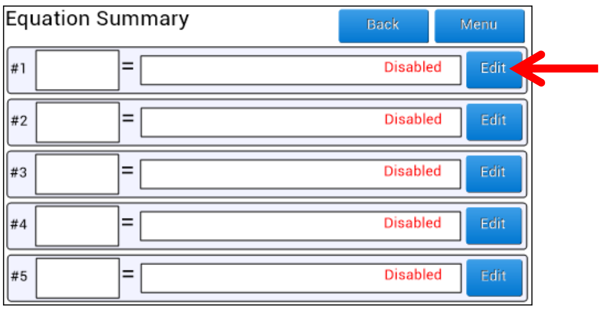
The next step is to assign Analogue Input Channel #3 as the Input to PID Controller #1. This is done using an equation. To navigate to the ‘Equations Summary’ screen press the ‘Expressions’ icon on the Main Menu as shown below.



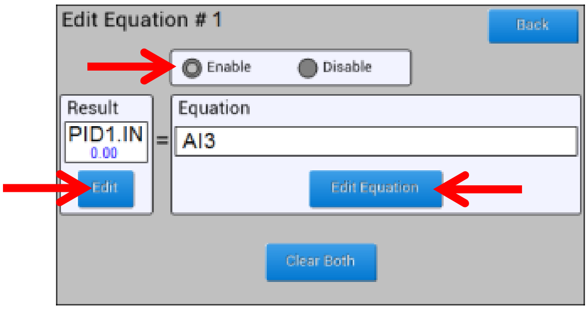
This shall display the ‘Expressions Menu’ screen; press the ‘Equations Setup’ icon as shown below.



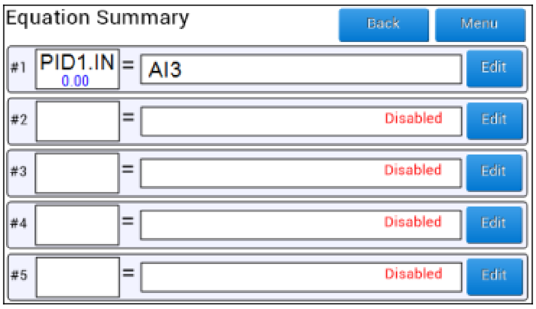
This shall display the ‘Equation Summary’ screen, press the corresponding ‘Edit’ button for Equation #1 as shown below.



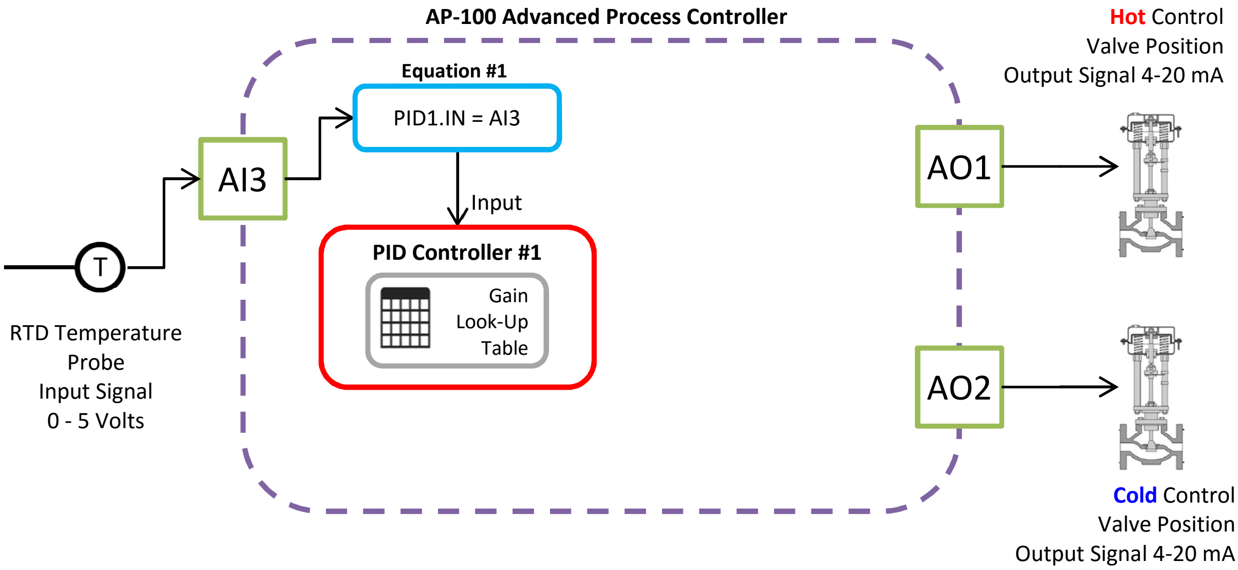
Below is the ‘Edit Equations #1’ screen. Press the ‘Edit Equation’ button and enter the Analogue Input Channel #3 ‘AI3’. Then press the Result’s ‘Edit’ button and enter ‘PID1.IN’ to assign the result of this equation to the Input of PID Controller #1. Press the ‘Enable’ radio button to start this equation’s execution. When finished press the ‘Back’ button.



The 'Equation Summary' screen shall look like the below. Notice that the Equation #1 fields shall be populated with the equation "PID1.IN = AI3".

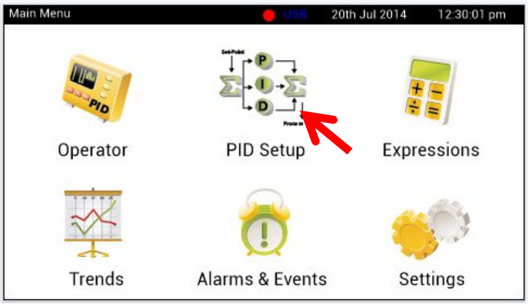


Below diagram depicts what has been created. Analogue Input Channel #3 (AI3) has been configured to receive the 0 – 5 volt temperature signal from the RTD Temperature probe. This signal value has been assigned as the Input signal for PID Controller #1 (PID1.IN) via 'Equation #1'.

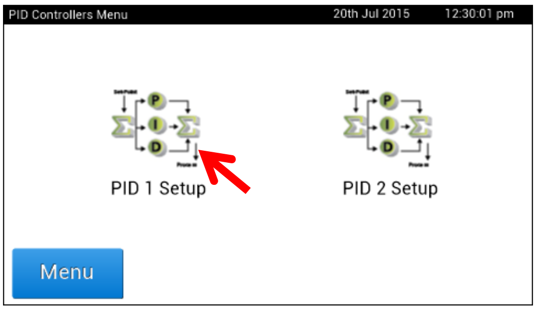


14.2. Setup PID Controller #1

To navigate to PID Controller #1, press the 'PID Setup' icon from the Main Menu. This shall display the PID Controller sub-menu.



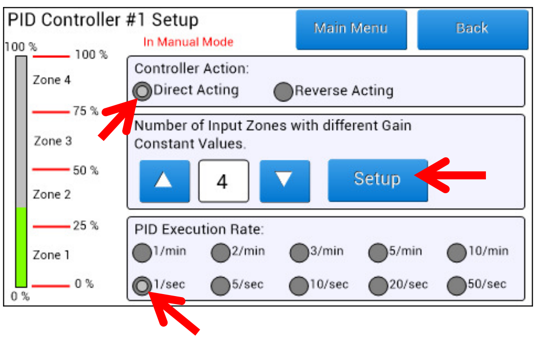
Then press the 'PID Controller Setup' icon, as shown below.



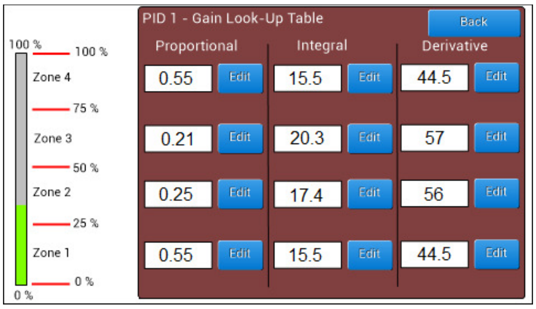
The first step is to determine whether this PID Controller is to be setup as 'Direct Acting' or 'Reverse Acting'. If the fluid temporary within the tank decreases below the Set-Point, the PID Controller will try to increase its Output signal (PID1.OUT) which will eventually ramp open the hot fluid control valve. Therefore, a positive change of PID Controller output shall cause a positive change in the process measurement, being the fluid temperature. Conversely, a negative change in of PID Controller output shall cause a negative change in the process measurement. Therefore, this PID Controller shall be setup as 'Direct Action', press the associated radio button as shown below.

As temperature control is not a fast process, the 'PID Execution Rate' shall be set for 1 execution cycles per second. Therefore, select the '1/sec' radio button as shown below.

For optimal control, this PID Controller shall be setup to have 4 input Zones. This means that the Input signal range shall be divided up into 4 Zones and there shall be a different set of PID gain values for each of these zones. Press the associated up arrow button, as shown below, to create 4 Input Zones. Then press the associated 'Setup' button to display the PID gain values.

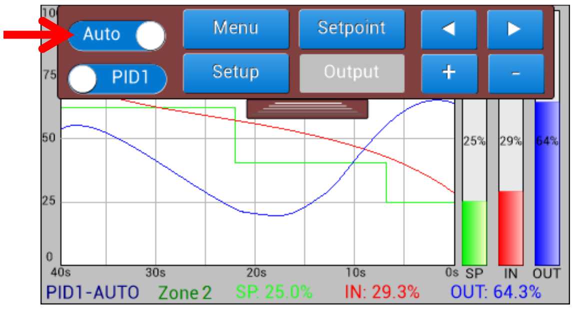


From using standard open-loop step response PID tuning practises the following PID gain values were obtains and entered in as shown below.



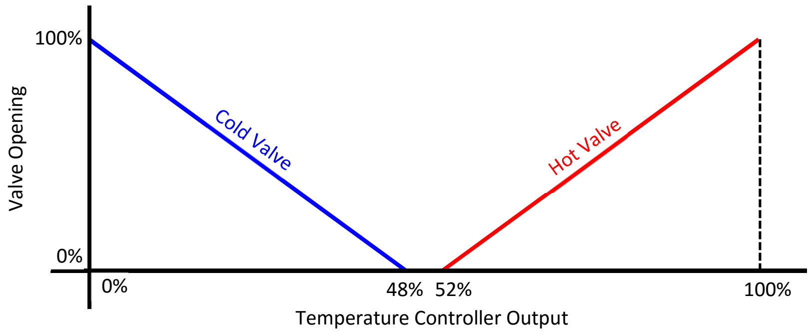
To start PID Controller #1 executing, it must be put into Automatic Mode. To do this, press the 'Operator' icon from the Main Menu, as shown below.

From the 'Drop-Down Tab Menu', set the top left toggle switch to 'Auto' mode as shown below. PID Controller #1 shall start executing and accepting its Set-Point values from the external controller.

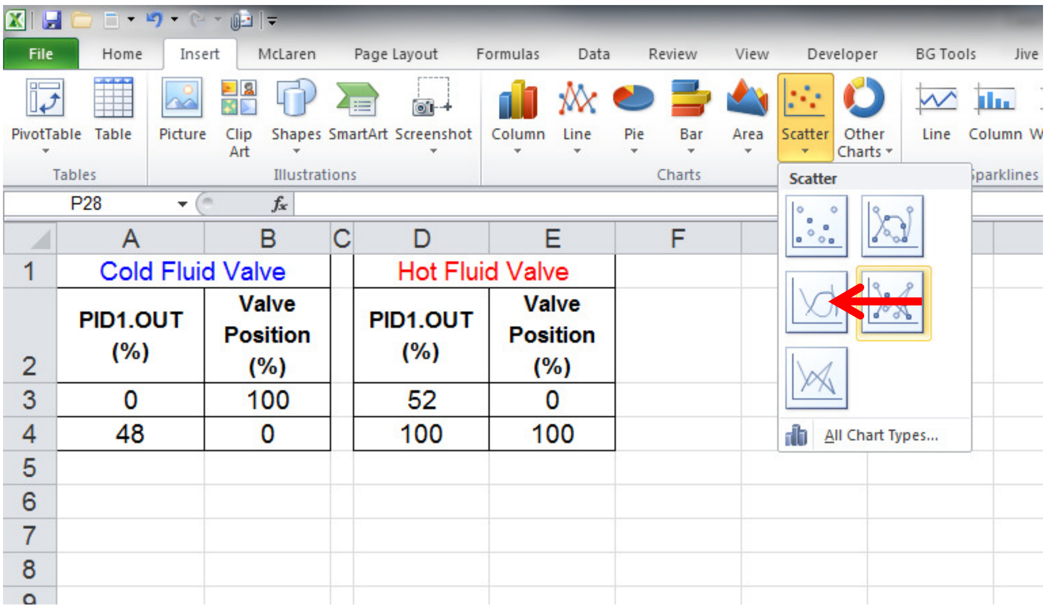


14.3. Analogue Output Signals Setup

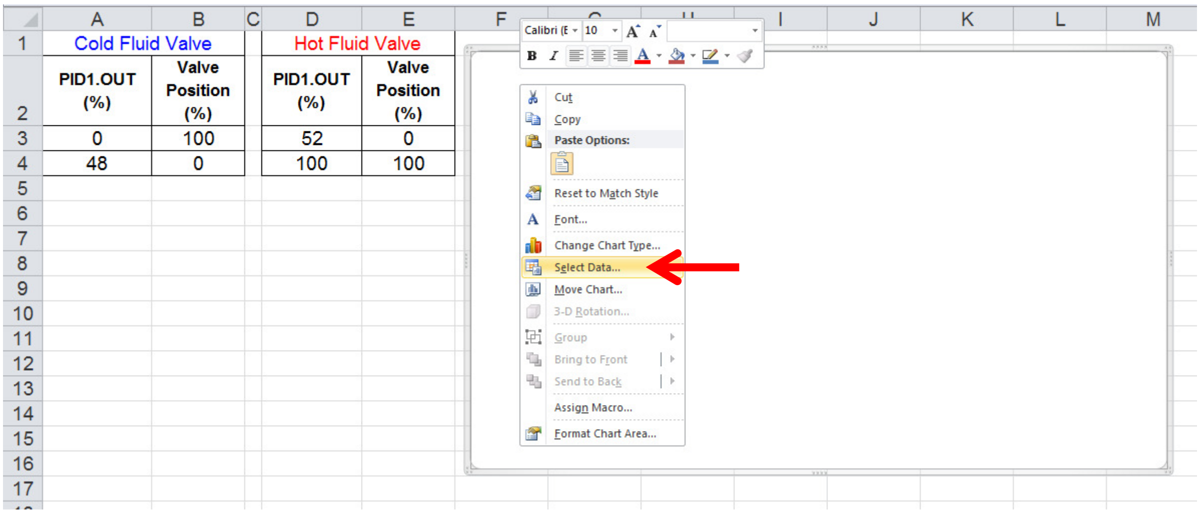
As descripted earlier, the 0% to 100% range of the Output of the PID Controller #1 is split in two between the two valves. If the controller output is between 0% and 48%, the cold fluid valve is operated. If the controller output is between 52% and 100%, the hot fluid valve will be operated.



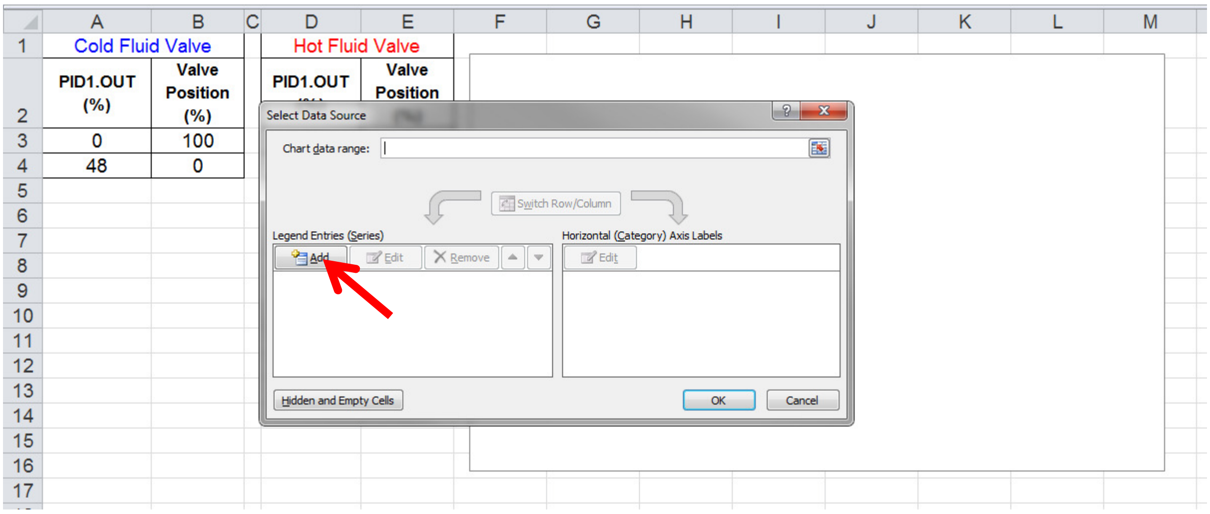
To achieve this, we must first derive the equations that translate the PID Controller #1 Output signal into valve positions. One way doing this is to use MS Excel. Enter the below data into MS Excel, then without highlighting any data, select from the top toolbar menu Insert > Charts > Scatter Chart.



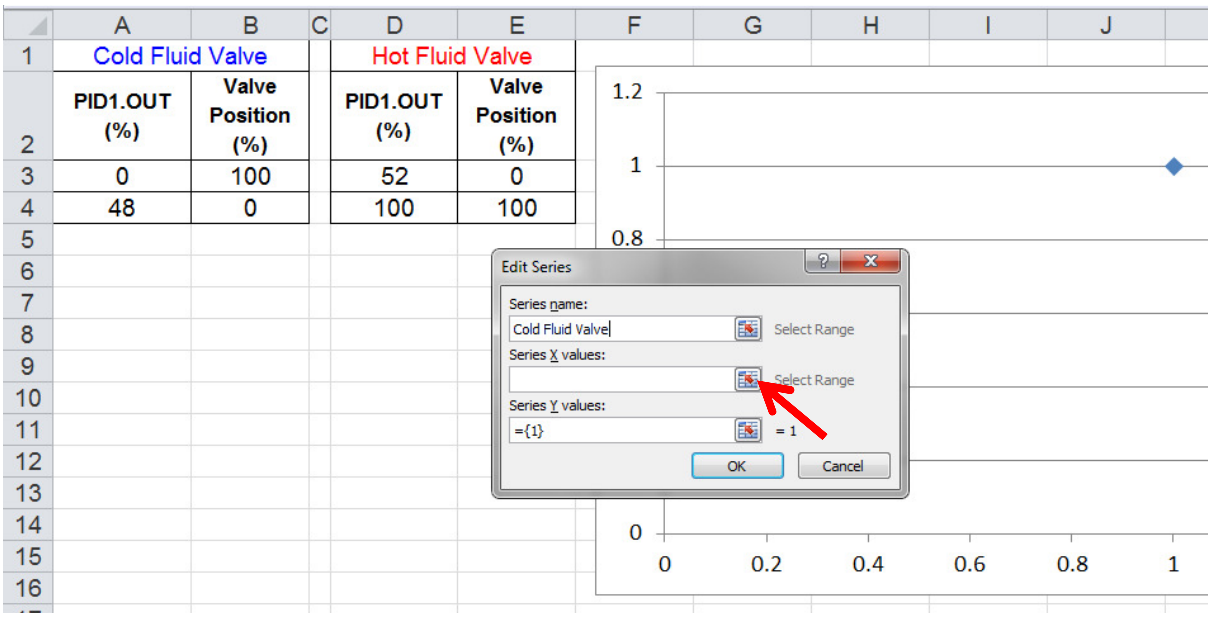
This shall display an empty graph with no data, as shown below. Right-Click on the empty graph area and chose 'Select Data…'.



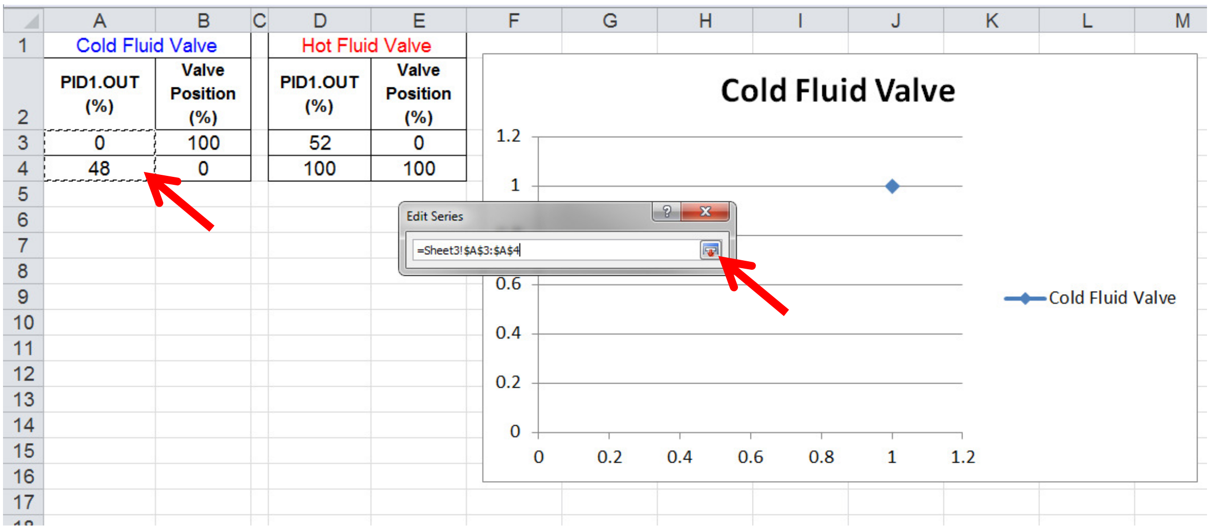
This shall display the ‘Select Source Data’ window. Click the ‘Add’ button as shown below.



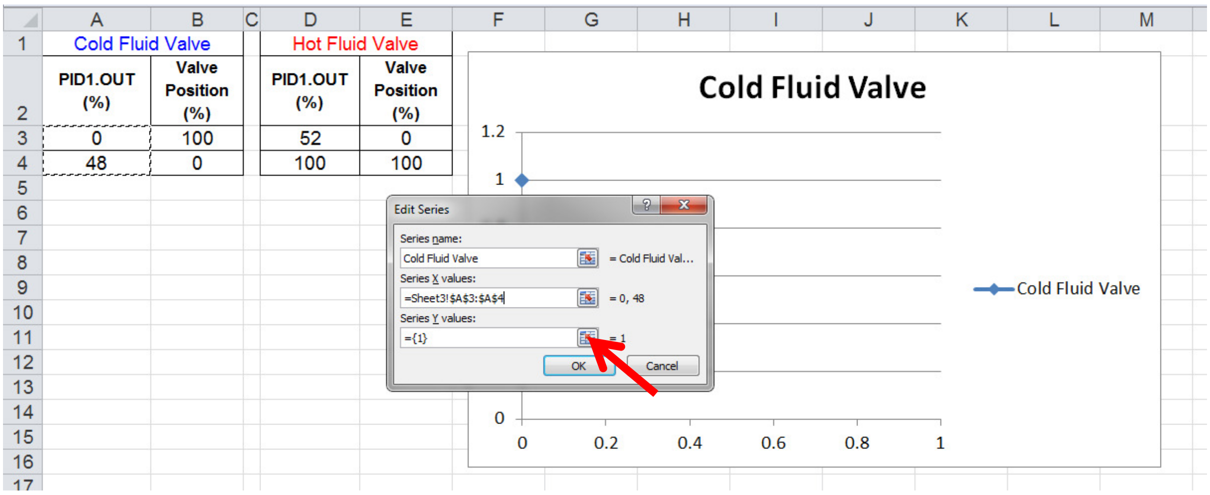
A new widow shall appear, in the ‘Series name:’ field enter “Cold Fluid Valve”. Then click on the button as shown below to add the data for the X-axis of the graph.



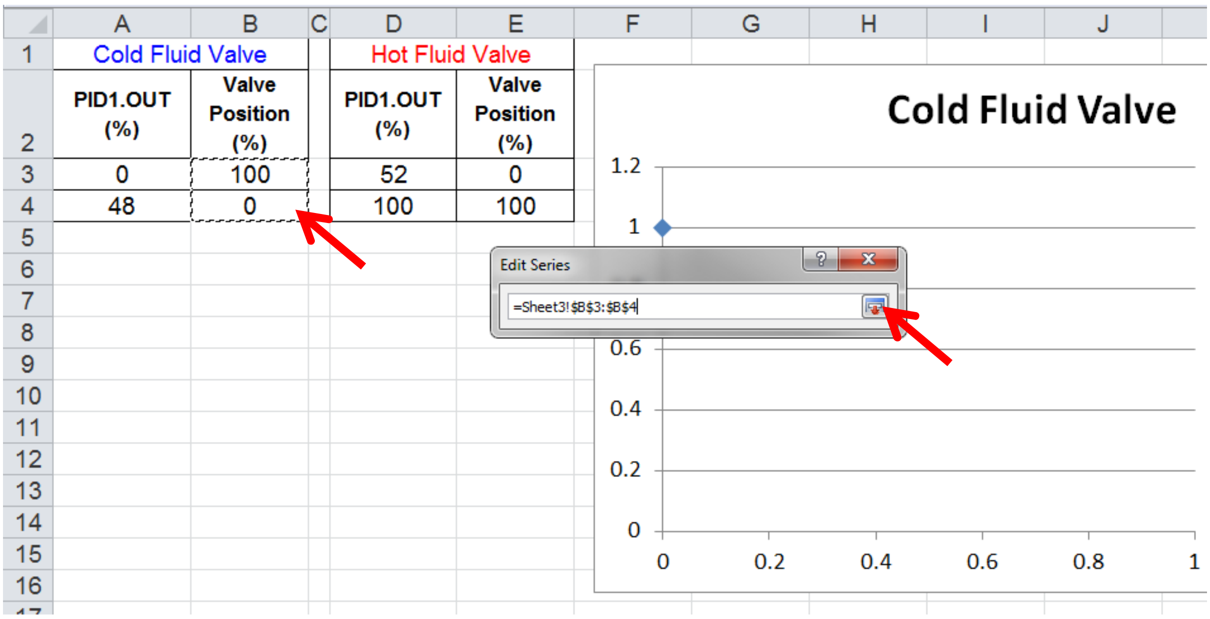
Highlight the data from cell ‘A3’ to cell ‘A4’, then click the button as shown below.



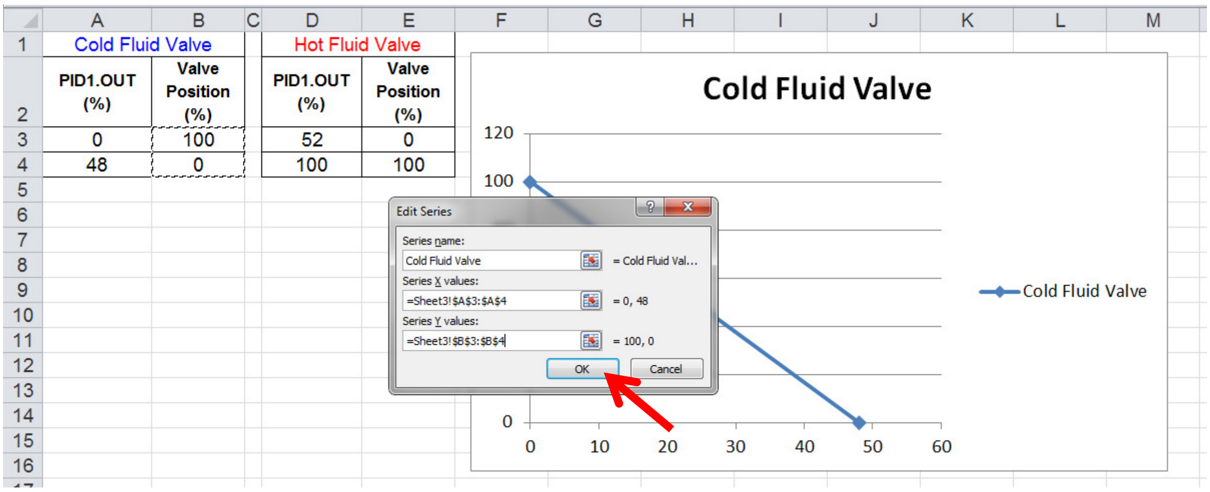
Now click the button as shown below, to select the data for the Y-axis.



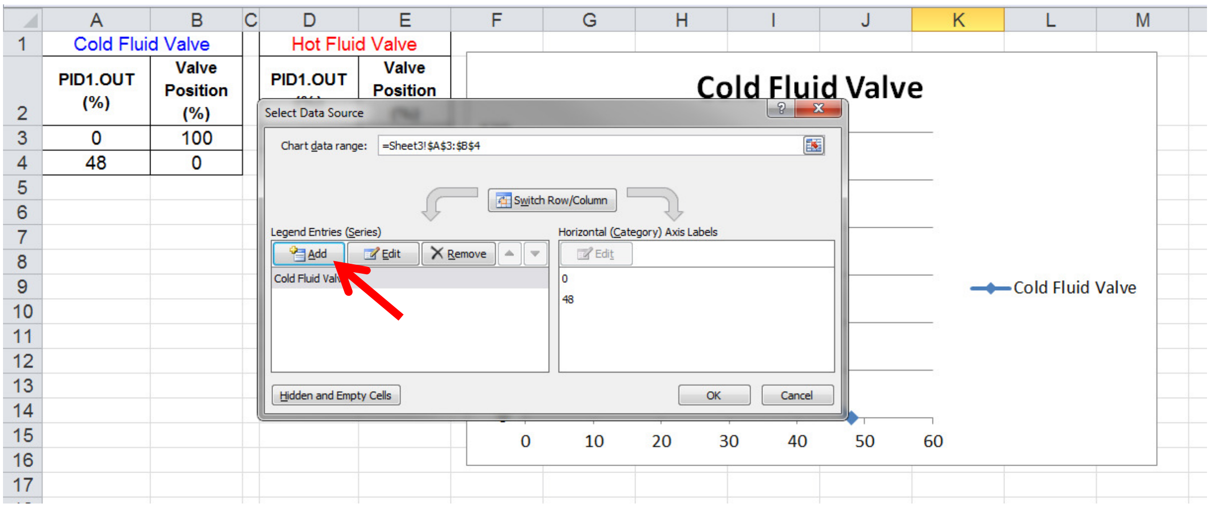
Highlight the data from cell ‘B3’ to cell ‘B4’, then click the button as shown below.



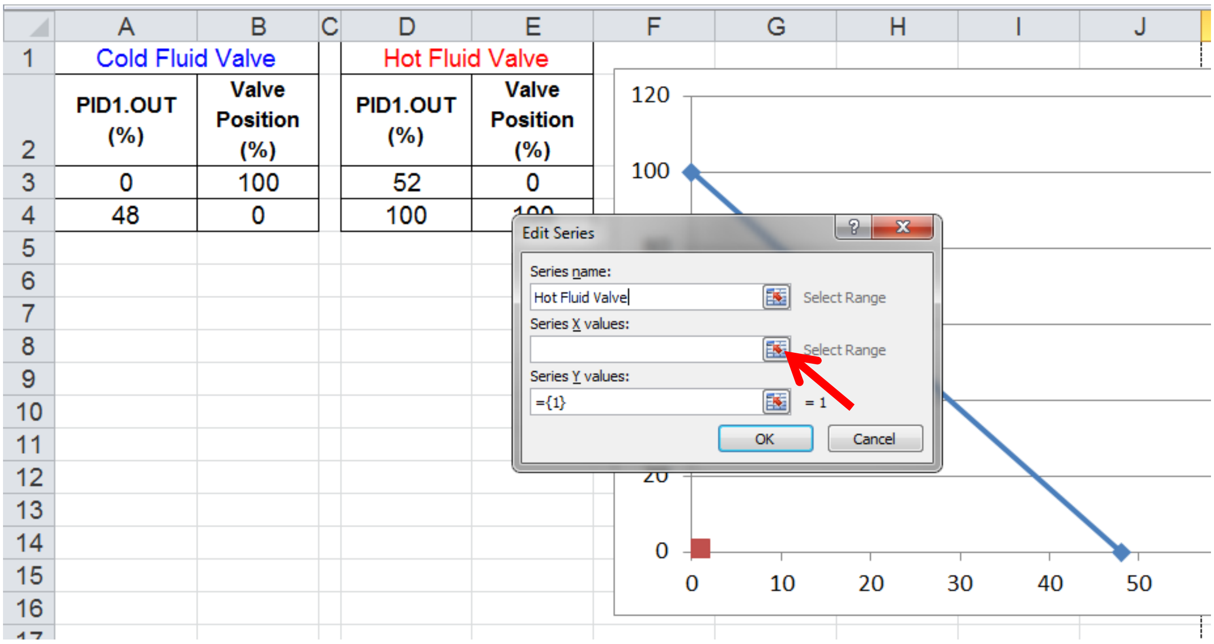
Now the data has been inputted for the cold fluid valve graph. Press the ‘OK’ button as shown below.



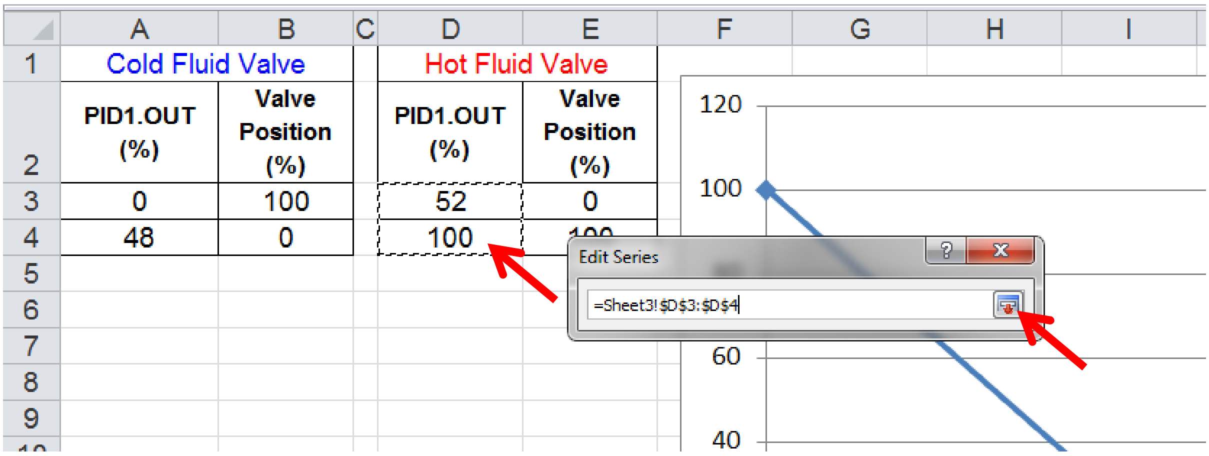
To create another graph for the hot fluid valve, click the ‘Add’ button again as shown below.



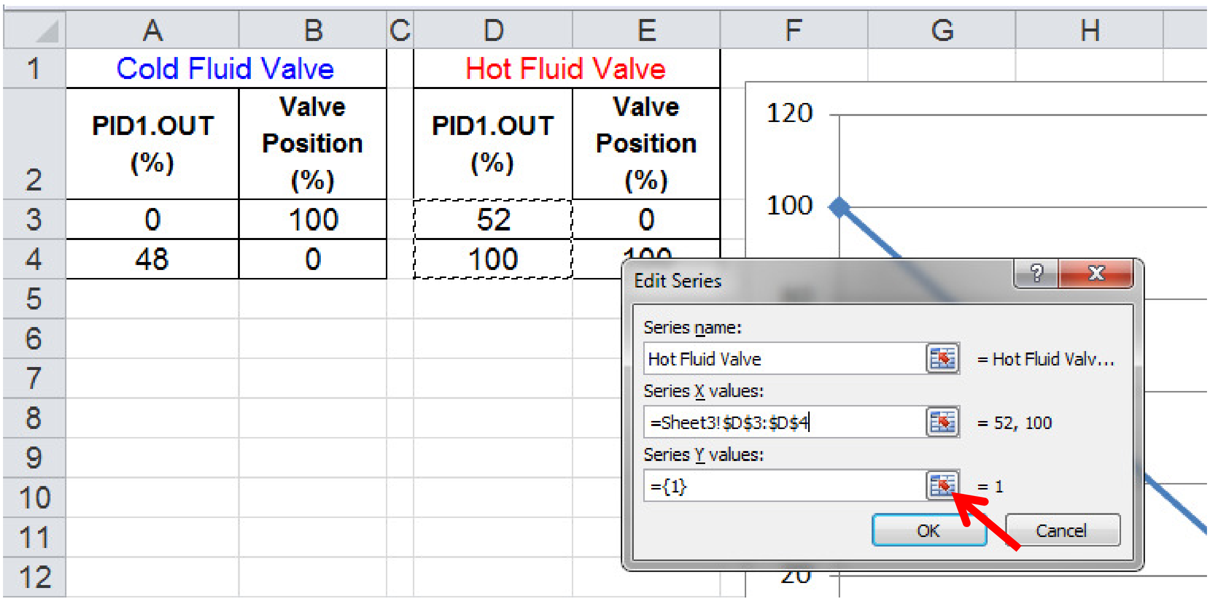
In the ‘Series name:’ field enter “Hot Fluid Valve”. Then click on the button as shown below to add the data for the X-axis of the graph.



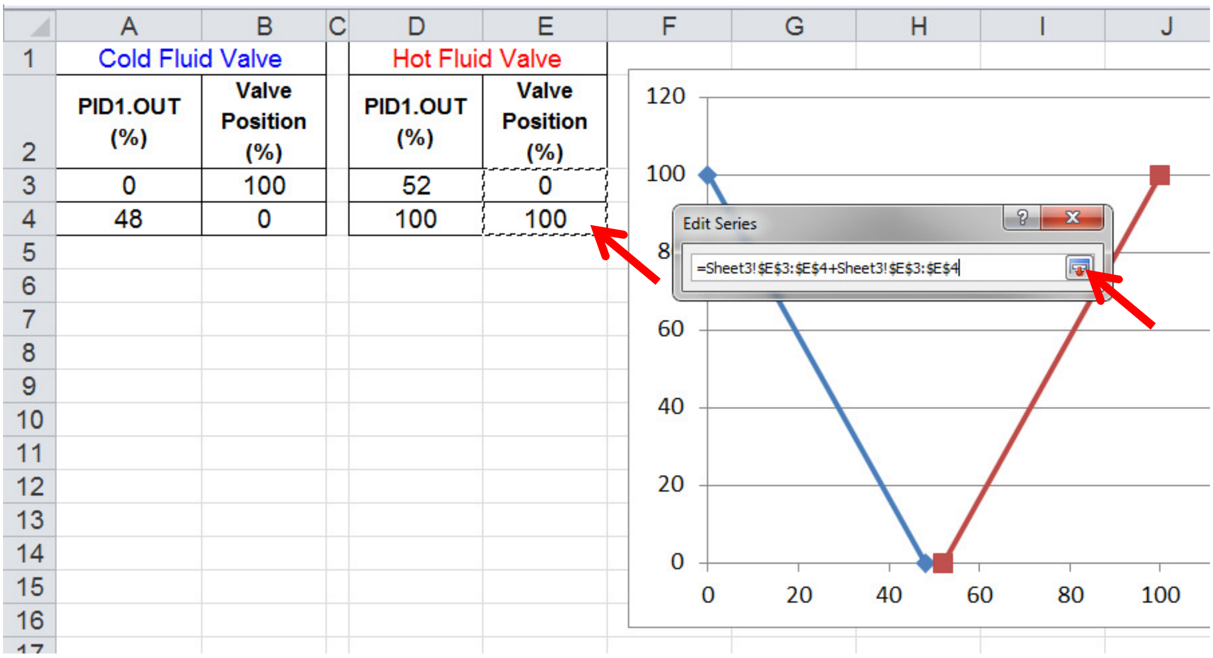
Highlight the data from cell ‘D3’ to cell ‘D4’, then click the button as shown below.



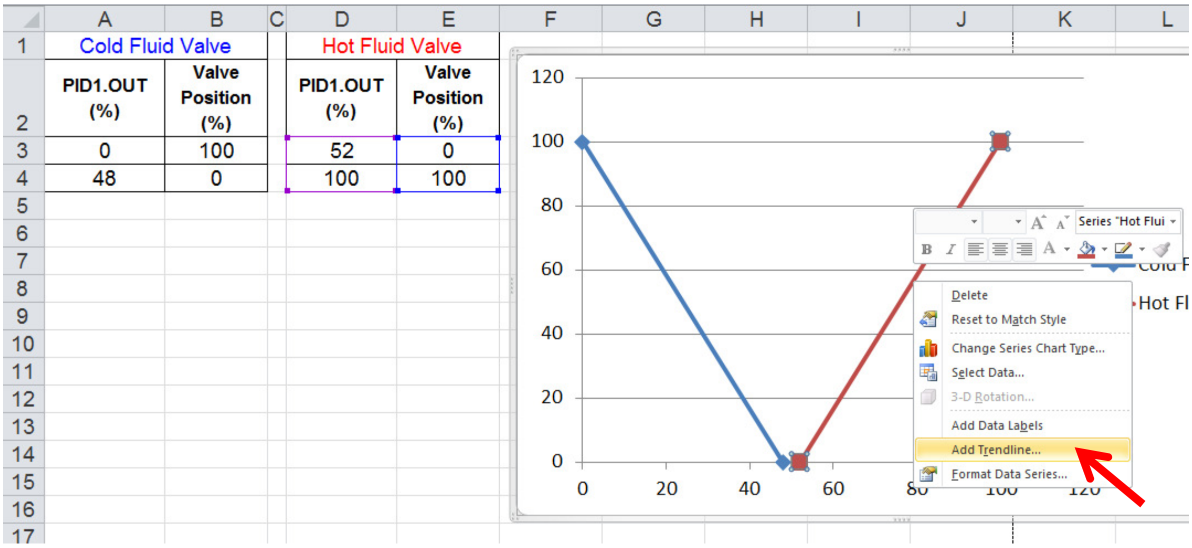
Now click the button as shown below, to select the data for the Y-axis.



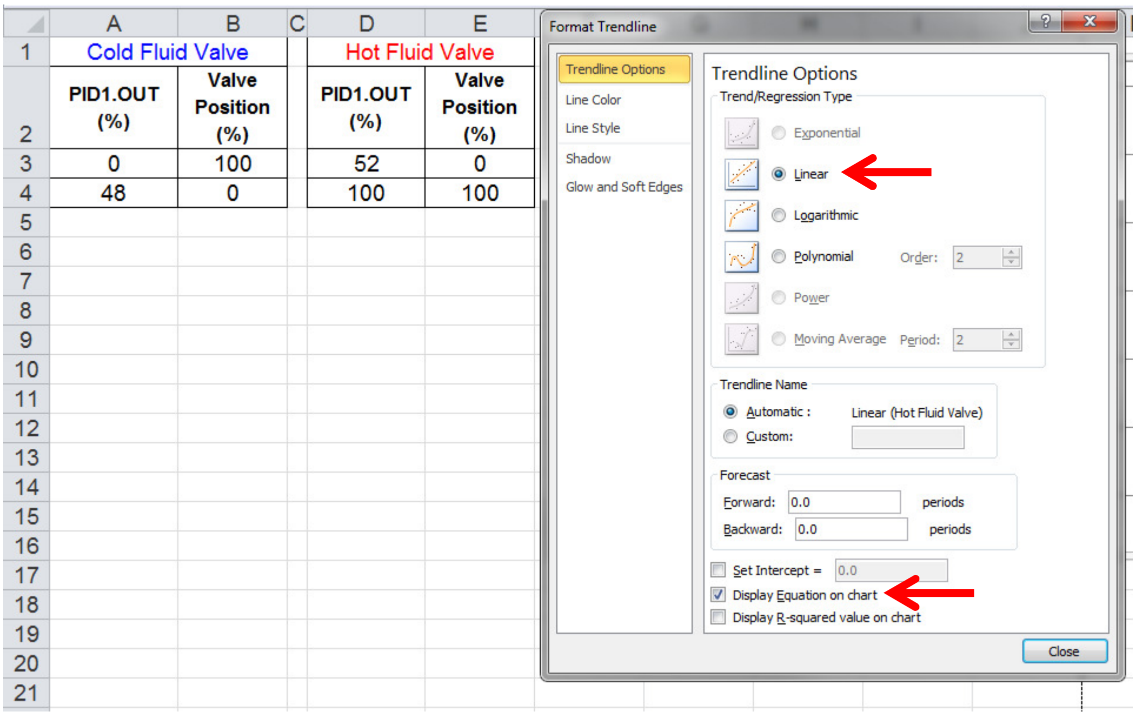
Highlight the data from cell 'E3' to cell 'E4', then click the button as shown below. Then click 'OK' twice for the next two windows.



Now the graphs of both the hot and cold fluid valves have been plotted, we need to obtain the equations for the Trendlines. To do this first right-click on the hot fluid valve graph and select ‘Add Trendline…’.



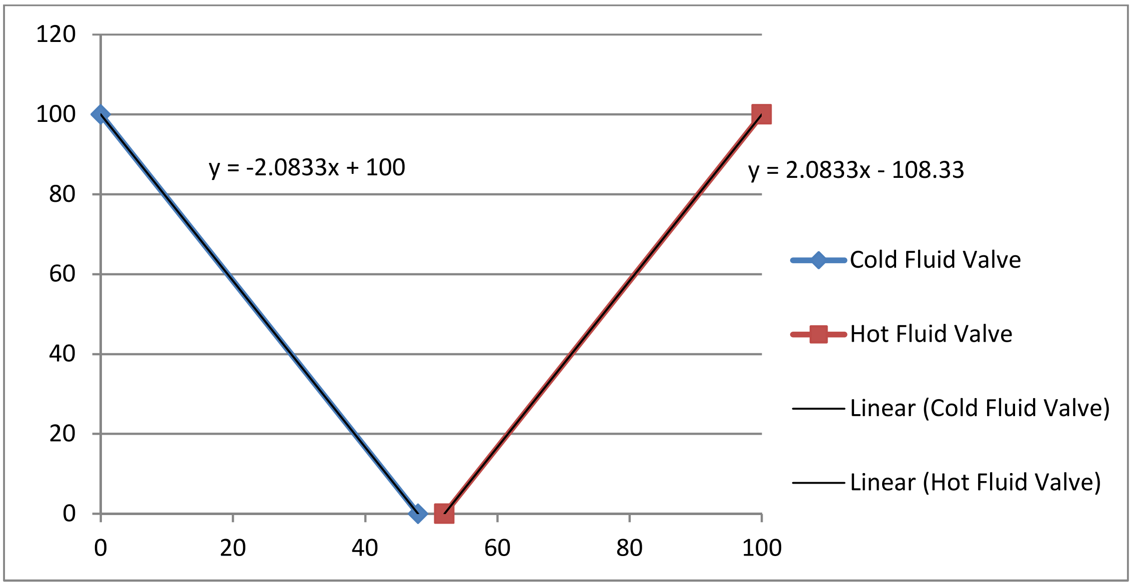
Select the ‘Linear’ radio button, and check the ‘Display Equation on chart’ checkbox. Then press ‘Close’.



Repeat the same steps above for the cold fluid valve. Right click on the cold fluid valve graph line and select ‘Add Trendline…’. Then select the ‘Linear’ radio button, and check the ‘Display Equation on chart’ checkbox. Then press ‘Close’.

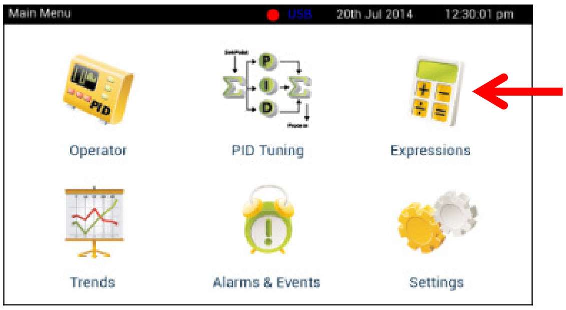
The graph should look like the below. The two equations to translate PID Controller #1 Output signal to valve position are as follows. The equations on the right have the device signals substituted.

Cold Fluid Valve:	y = -2.0833x + 100	→	AO2 = -2.0833 * PID1.OUT + 100
Hot Fluid Valve:	y = 2.0833x – 108.33	→	AO1 = 2.0833 * PID1.OUT – 108.33

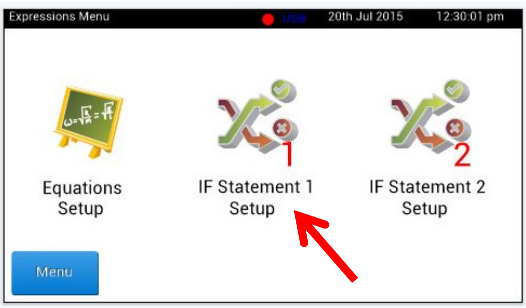


The above two equations shall be used to link the Output signal of PID Controller #1 the respective valves. However, the Output signal should only be linked to the one of the valves at a time. A conditional IF Statement shall be configured to use only one of the above equations at a time, depending on whether the PID Controller #1 Output signal is above or below 50%.

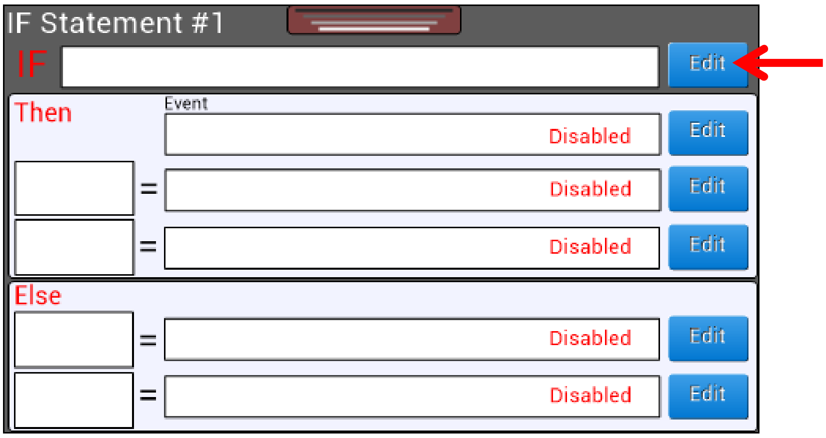
To configure an IF Statement, navigate to the ‘Expressions Menu’ by pressing the ‘Expressions’ icon from the Main Menu, as shown below.



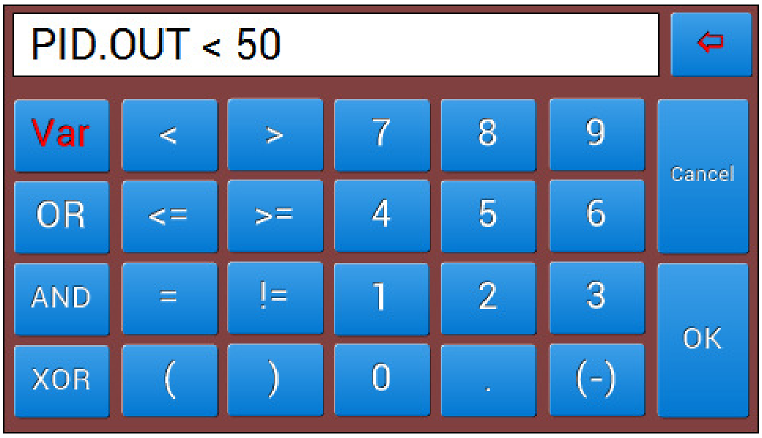
Press the ‘IF Statement 1 Setup’ icon as shown below.



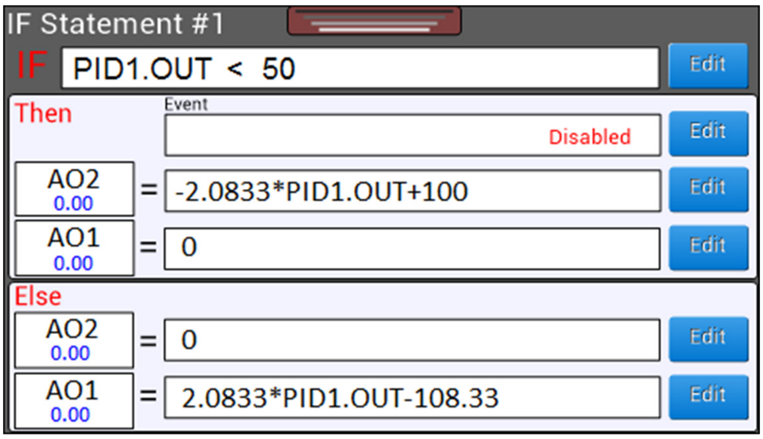
Below shows the IF Statement #1 setup screen. The first step is to enter the logical IF expression by pressing the corresponding ‘Edit’ button as shown below.



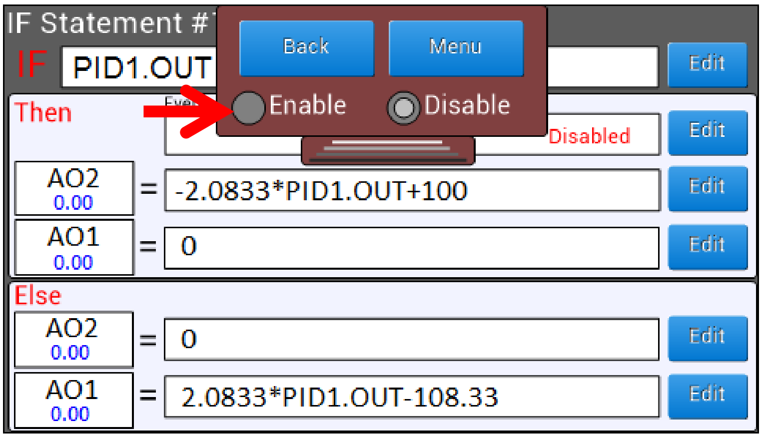
Below shows the IF Statement #1 edit screen. Enter the expression “PID1.OUT < 50” as shown below. Press the ‘Var’ button to select the “PID1.OUT” signal. Press ‘OK’ when finished.



Edit the rest of the equations in the same way as the equation for the Input Signal, by pressing the corresponding ‘Edit’ button for each equation. Enter the equations and result signals as per the below.

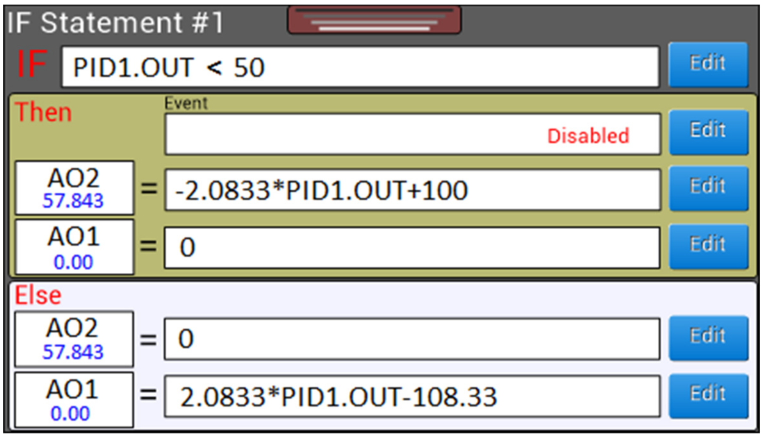


Once the IF Statement #1 has been setup, it needs to be enabled to start its execution. To do this, press the tab at the top to show the Drop-Down menu, as shown below. Then press the ‘Enable’ radio button, then press the tab again to close the Drop-Down menu.

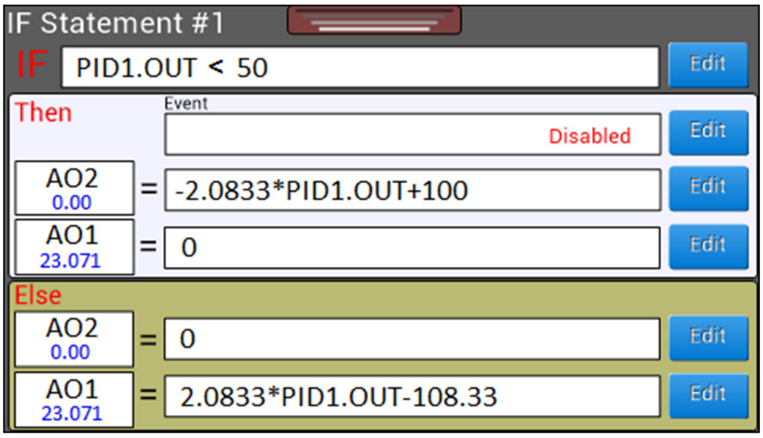


As the IF Statement #1 is executing the 'Then' or 'Else' sections shall turn green depending on whether or not the logical 'IF' statement is evaluated to the true or false. When a section turns green, the equations (and Event) within the section shall be executed.

In the below, the logical 'IF' statement "PID1.OUT < 50" has been evaluated to be <u>True</u> as the Output signal (PID1.OUT) from PID Controller #1 is <u>less</u> than 50%.



In the below, the logical 'IF' statement "PID1.OUT < 50" has been evaluated to be <u>False</u> as the Output signal (PID1.OUT) from PID Controller #1 is <u>greater</u> than 50%.

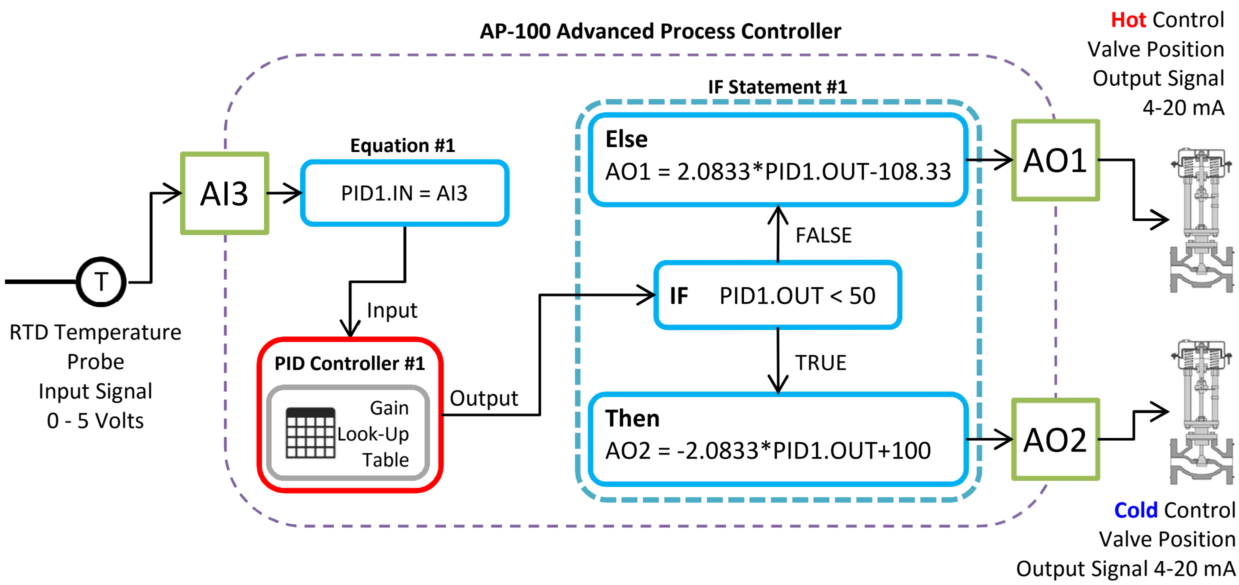


14.4. Conclusion

Below visually depicts what has been setup.

In this case study the AP-100 Advances Process Controller is being used to control the temperature of fluid within a tank with its internal PID Controller. The AP-100 device reads the fluid temperature from an RTD temperature probe that outputs a 0 to 5 Volt signal for 0 to 200˚C respectively. The AP-100 shall control the fluid temperature by manipulating two control valves. One control valve is on a hot fluid inlet line and the other is on a cold fluid inlet line into the tank. Both control valves receive a 4 to 20 mA signal for 0% to 100% open.

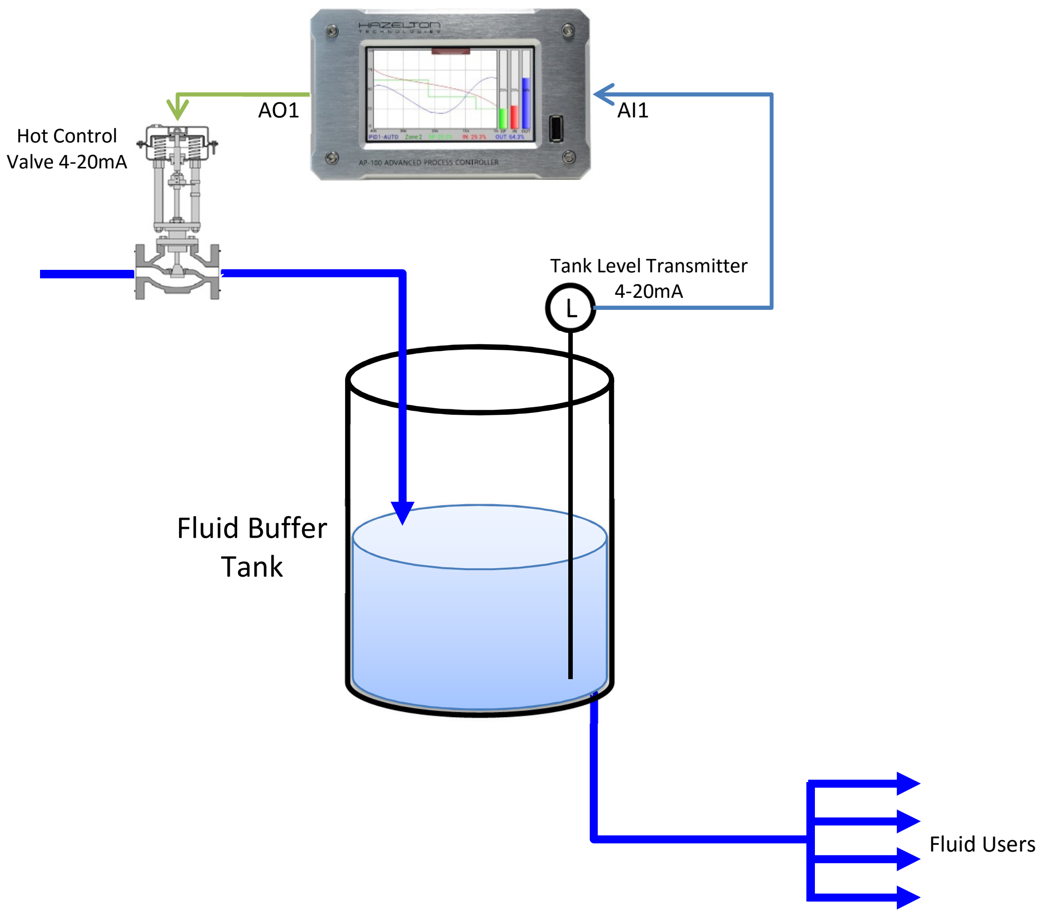
The 0% to 100% range of the Output of the PID Controller is split in two between the two valves. If the controller output is between 0% and 48%, the cold fluid valve is operated. If the controller output is between 52% and 100%, the hot fluid valve will be operated. At 52% controller output, the hot fluid valve starts to open and it is fully open at 100%. There is a dead-band between 48% and 52% of controller output where both valves remain closed.



15. CASE STUDY – FEED-FORWARD PID CONTROL

This case study shall analyse a Fluid Buffer Tank level PID controller scenario and how to implement a Feed-Forward PID Controller scheme to improve performance. The process under control is illustrated below. The level within a Fluid Buffer Tank is controlled by a control valve on an inlet line to the tank. The level of the Fluid Buffer Tank is measured with a Level Transmitter. There is an outlet line from the Fluid Buffer Tank to supply fluid to the downstream users.

The AP-100 Advanced Process Controller is used to read the Level Transmitter's 4-20 mA signal and controls the control valve by outputting a 4-20mA signal. The AP-100 device uses an internal PID controller to receive the input level measurement signal and to produce the outputted control valve position signal. The fluid level Set-Point is entered into the AP-100 device through the touchscreen display.



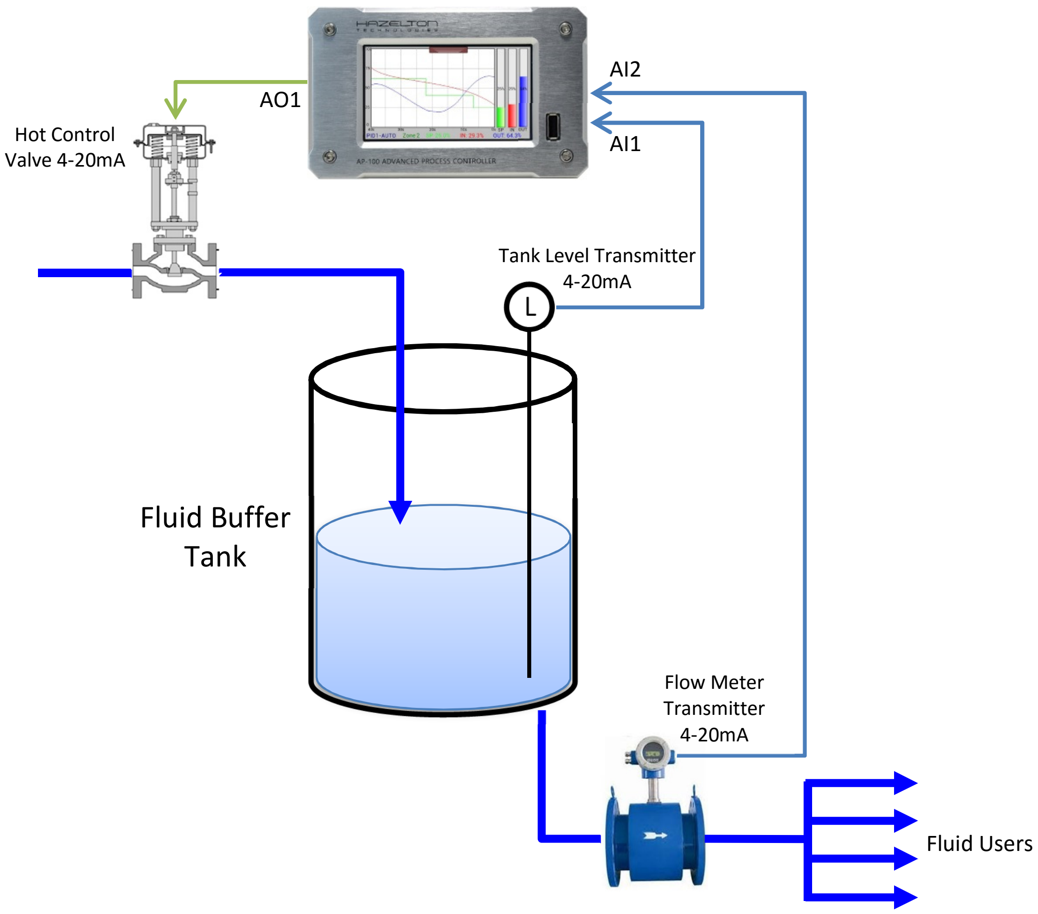
Consider that a process change can occur downstream from the Fluid Buffer Tank by one or more of the user that will cause a disturbance to the level measurement.

The traditional PID controller takes action only when the Level Measurement has been moved from Set-Point, to produce a controller error:

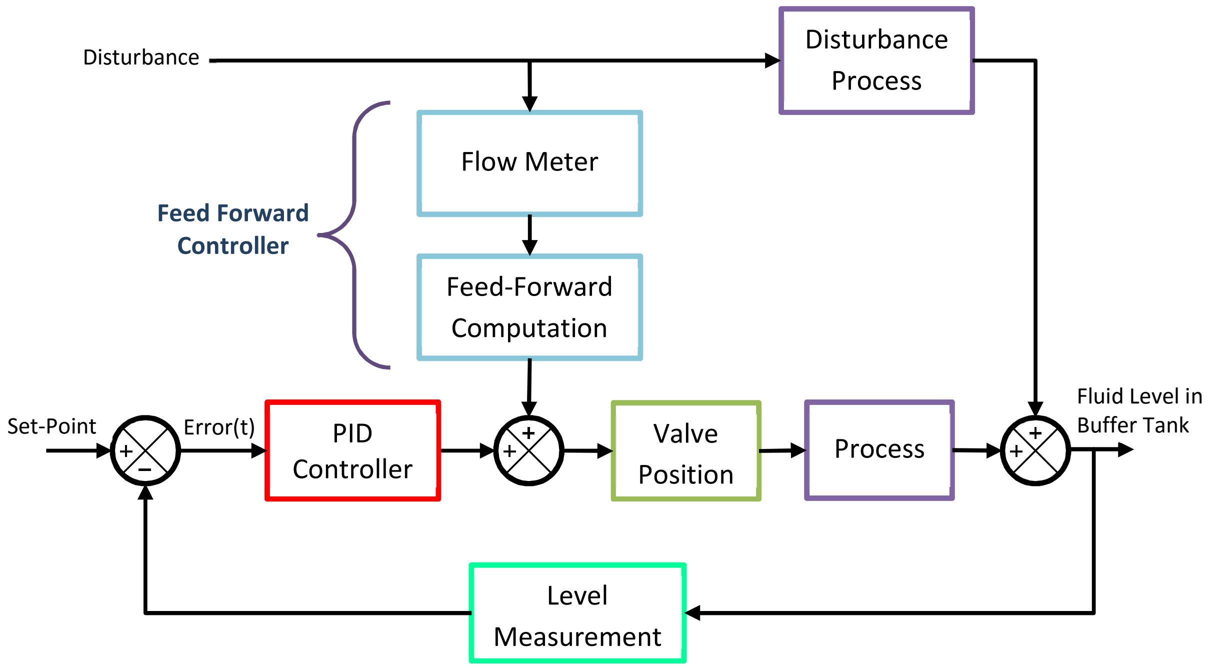
Error(t) = Set-Point – Level Measurement

Thus, disruption to stable operation is already in progress before a feedback controller first begins to respond. From this view, a feedback strategy simply starts too late and at best can only work to minimize the upset as events unfold.

In contrast, a feed-forward controller measures the disturbance, while it is still distant. As shown below, a feed-forward element has been added which is a flow meter on the outlet line of the Fluid Buffer Tank. This flow meter is used to measure the disturbance caused by downstream users, and shall be used to predict the impact that it will have on the fluid level and then computes pre-emptive control actions. The goal is to maintain the fluid level to the controller Set-Point value (fluid level = Set-Point) throughout the disturbance event.



The control system block diagram for this feed-forward PID controller is shown below. The “Disturbance” input is one or more of the downstream users having a sudden and significant change in fluid usage.



The feed-forward computation is a function of the flowrate out of the tank verse the change in level.

$$V_{Out} = C_d \, A_{Output} \sqrt{2\, g\, h}$$

Where:

V_{Out}	= The fluid flow rate out of the tank (m^3/s).
C_d	= discharge coefficient.
A_{Output}	= Cross sectional area of the output pipe (m^2).
g	= gravity (9.81 m/s^2).
H	= Height of the tank (m).

Re-arrange to solve for the fluid height 'h' give the following.

$$h = \frac{\left(\frac{V_{Out}}{C_d \times A_{Output}}\right)^2}{2 \cdot g} \qquad \text{(Equation 1)}$$

The controlled element is a control valve's position signal connected to Analogue Output Channel #1 (AO1). Now an equation needs to be derived to link the relationship between the rate of change of the control valves position (ΔAO1) and the rate of change of the fluid level (Δh).

$$\Delta AO1 = \Delta h \cdot B + C \qquad \text{(Equation 2)}$$

Where B and C are constants. Substituting Equation 2 into Equation 1 gives the following.

$$\Delta AO1 = \left(\frac{\left(\frac{\Delta V_{Out}}{C_d \times A_{Output}} \right)^2}{2 \cdot g} \right) \cdot B + C \qquad \text{(Equation 3)}$$

The Analogue Input Signal 'AI2' for the fluid flow rate shall be substituted in to Equation 3 for V_{Out}. The constants shall also be insert in to Equation 3 which shall give the following equation. The rate of change of the control valves position (ΔAO1) shall be substituted with an Intermediate Variable #1 (Var1).

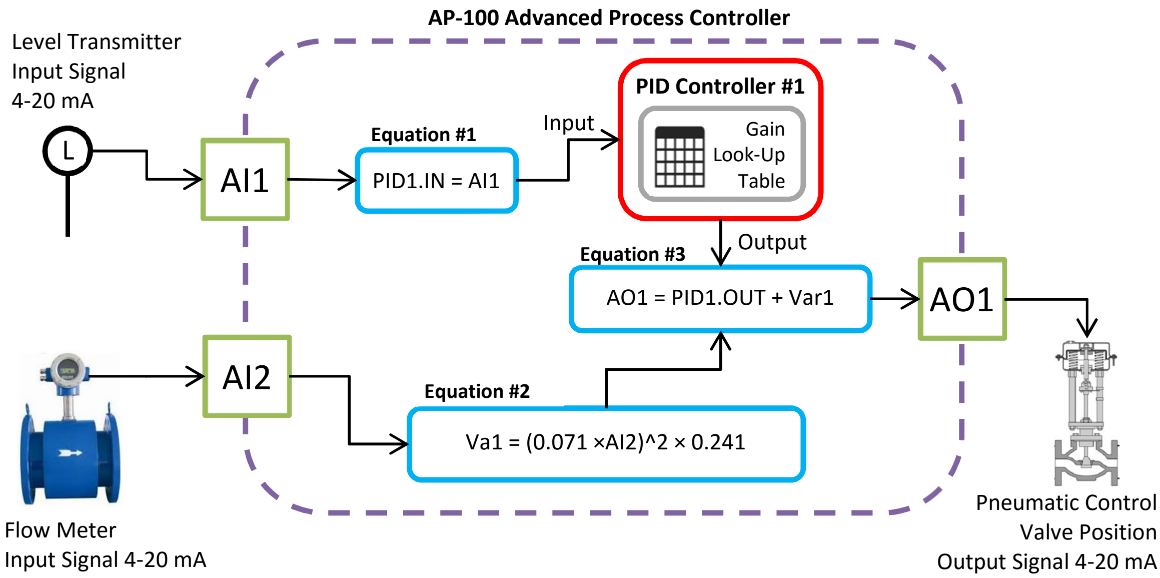
$$Var1 = (0.071 \times AI2)^2 \times 0.241 \qquad \text{(Equation 4)}$$

Hence the Equation 4 above is the feed-forward computation equation. To link this feed-forward valve to the PID Controllers #1 Output signal and hence the control valve's position signal (Analogue Output Channel #1), the following equation is derived.

$$AO1 = Var1 + PID1.OUT \qquad \text{(Equation 5)}$$

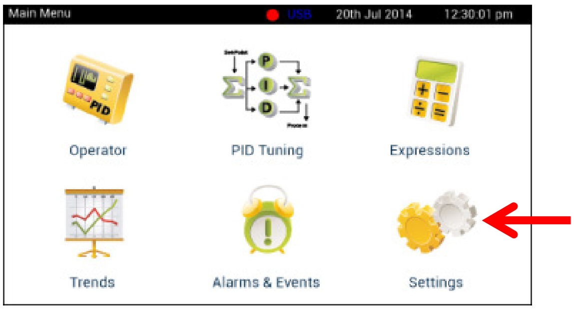
Both equations 4 and 5 above shall be implemented in the AP-100 device as shown in the following steps.

The below diagram visually depicts the equations that shall be setup internally within the AP-100 Advanced Process Controller. The following steps shall explain how to link the Level transmitter signal at Analogue Input CH #1 (AI1) to the PID Controller #1's Input signal using Equation #1. Then the Feed-Forward computation shall be setup with Equation #2. That evaluates the Flow meter signal from at Analogue Input CH #2 (AI2). Then Equation #3 shall be used to produce the inlet line Control valve's position signal from the PID Controller's Output signal and the result from the Feed-Forward Computation of Equation #2. The result from Equation #3 shall be sent to the Control Valve through Analogue Output CH #1.



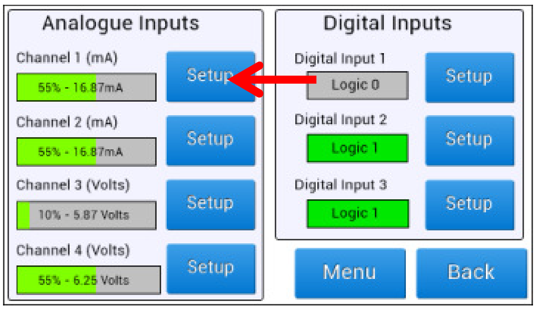
15.1. Tank Level Input Signal Setup

The Fluid Buffer Tank has its level measured with a Level Transmitter that outputs a 4-20 mA signal for 0% to 100% level respectively. This signal is read by the AP-100 device through Analogue Input Channel #1. The first step is to configure the Analogue Input Channel #1 to read this signal. To navigate to the Analogue Input Channel #1 setup screen press the 'Settings' icon on the Main Menu as shown below.

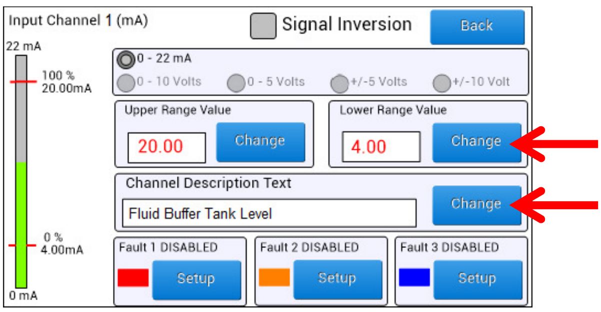


Press the 'Input Channels Setup' icon as shown below.

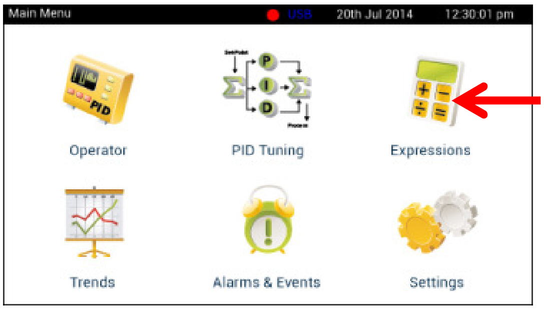
Press the corresponding 'Setup' button for Analogue Input Channel #1.



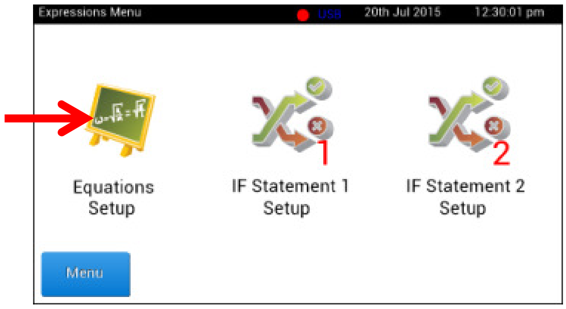
Shown below is the Analogue Input Channel #1 setup screen. Change the minimum and maximum ranges to 4mA and 20mA respectively, by pressing the corresponding 'Change' buttons. Then press the corresponding 'Change' button for the 'Channel Description Text' and change the description to "Fluid Buffer Tank Level". Press the 'Back' button and navigate to the Main Menu when finished.



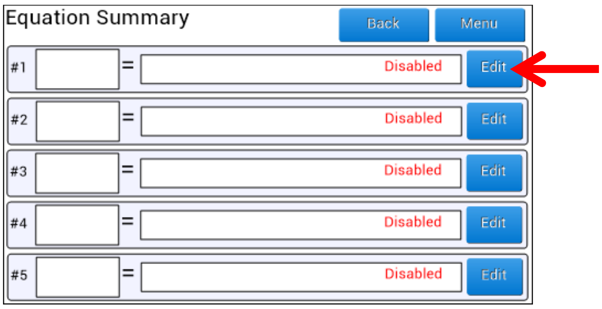
The next step is to assign Analogue Input Channel #1 as the Input to PID Controller #1. This is done using an equation. To navigate to the 'Equations Summary' screen press the 'Expressions' icon on the Main Menu as shown below.



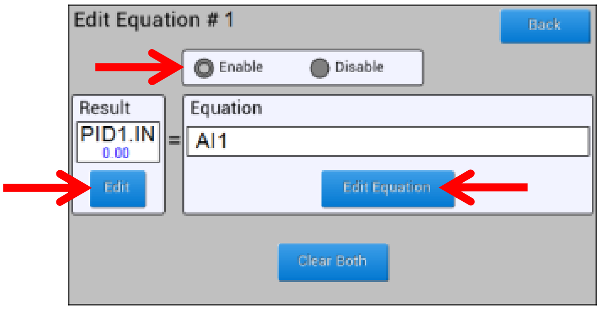
This shall display the 'Expressions Menu' screen; press the 'Equations Setup' icon as shown below.



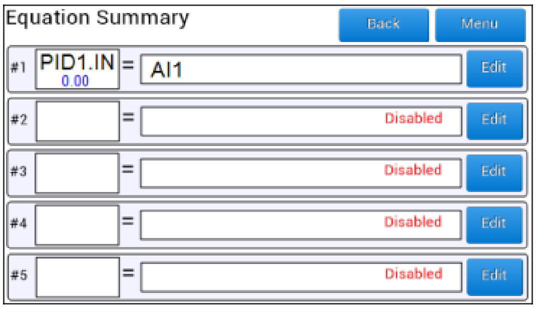
This shall display the 'Equation Summary' screen, press the corresponding 'Edit' button for Equation #1 as shown below.



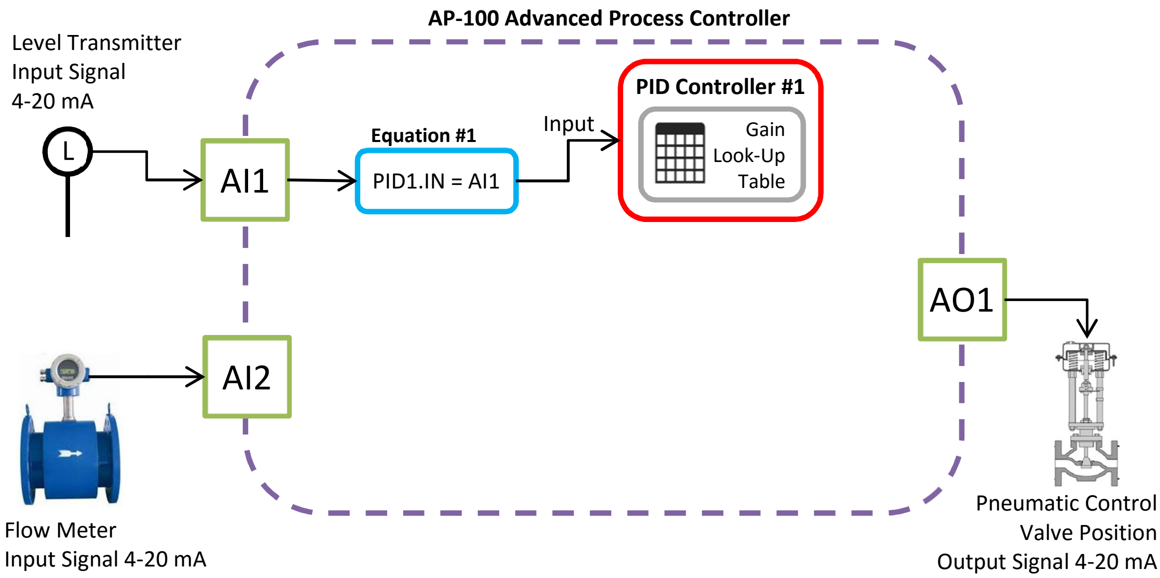
Below is the 'Edit Equations #1' screen. Press the 'Edit Equation' button and enter the Analogue Input Channel #1 'AI1'. Then press the Result's 'Edit' button and enter 'PID1.IN' to assign the result of this equation to the Input of PID Controller #1. Press the 'Enable' radio button to start this equation's execution. When finished press the 'Back' button.



The ‘Equation Summary’ screen shall look like the below. Notice that the Equation #1 fields shall be populated with the equation “PID1.IN = AI1”.

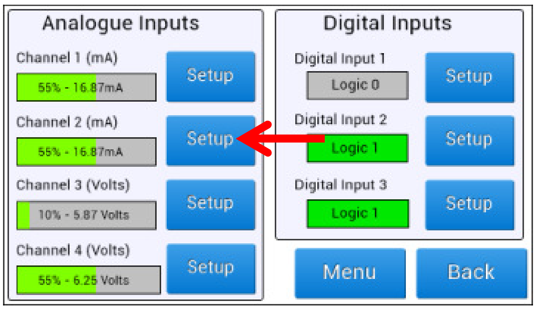


Below diagram depicts what has been created. Analogue Input Channel #1 (AI1) has been configured to receive the 4-20mA level signal from the Tank Level Transmitter. This signal value has been assigned as the Input signal for PID Controller #1 (PID1.IN) via ‘Equation #1’.

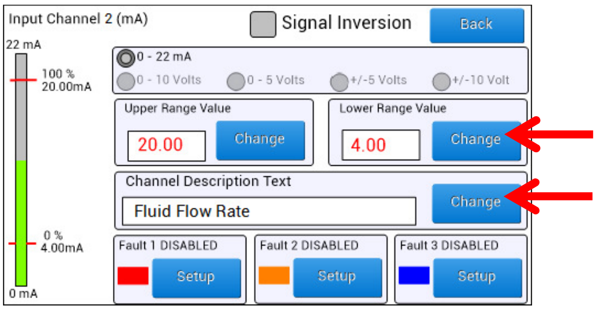


15.2. Flow Rate Out of Tank Input Signal Setup

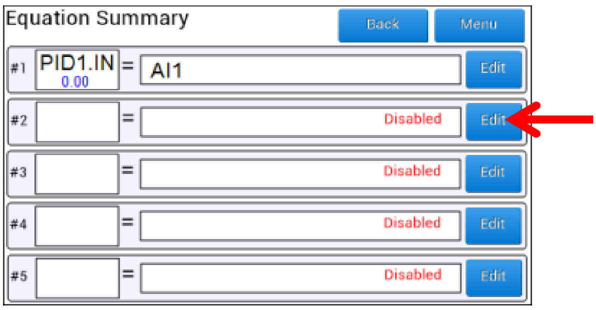
From the ‘Input Channels Setup’ page, press the corresponding ‘Setup’ button for Analogue Input Channel #2.



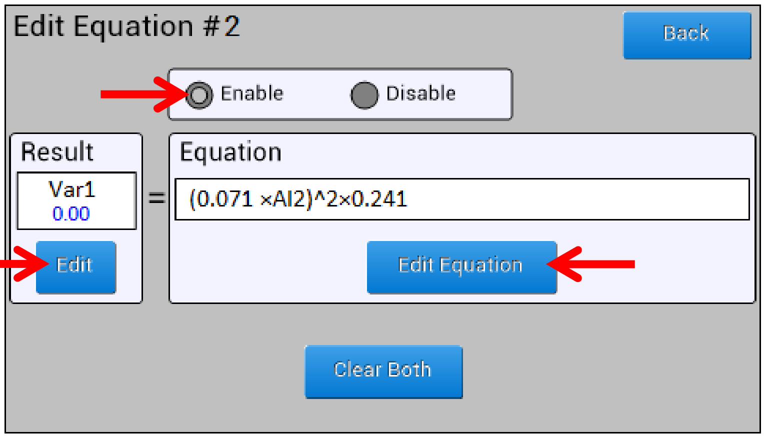
Shown below is the Analogue Input Channel #2 setup screen. Change the minimum and maximum ranges to 4mA and 20mA respectively, by pressing the corresponding ‘Change’ buttons. Then press the corresponding ‘Change’ button for the ‘Channel Description Text’ and change the description to “Fluid Flow Rate”. Press the ‘Back’ button and navigate to the Main Menu when finished.



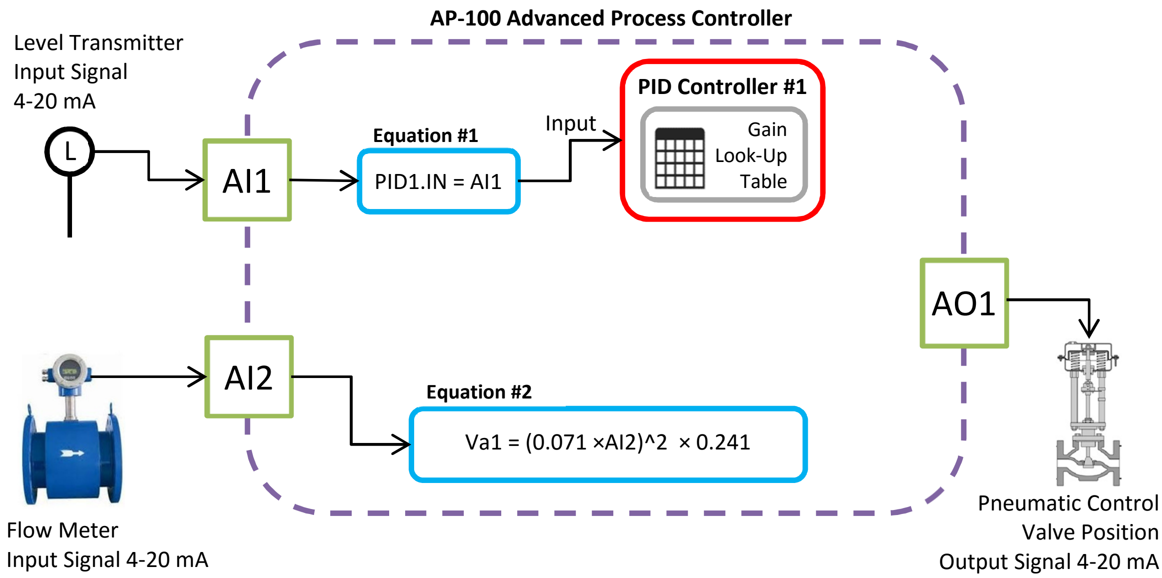
As before navigate to the ‘Equation Summary’. The Fluid Flow Rate signal (AI2) shall be used in an equation (Equation 4 as derived above) for the feed-forward computation in Equation #2. Press the corresponding ‘Edit’ button for Equation #2 as shown below.



Below is the ‘Edit Equations #2’ screen. Press the ‘Edit Equation’ button and enter the “(0.071 ×AI2)^2×0.241”. Then press the Result’s ‘Edit’ button and enter ‘Var1’ to assign the result of this equation to the Intermediate Variable #1. Press the ‘Enable’ radio button to start this equation’s execution. When finished press the ‘Back’ button.

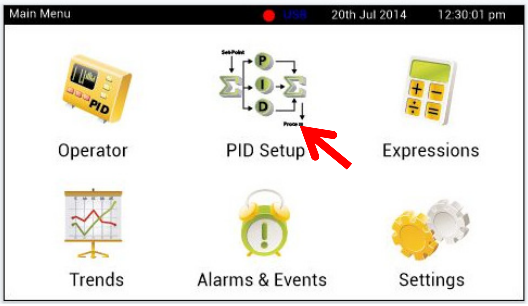


Below diagram depicts what has been created. Analogue Input Channel #2 has been setup to receive the Fluid Flow Rate 4-20 mA signal. Equation #2 has been setup to implement the feed-forward computation, as derived from Equation 4 above.

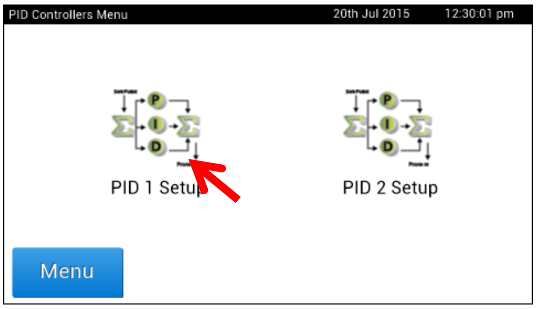


15.3. Setup PID Controller #1

To navigate to PID Controller #1, press the 'PID Setup' icon from the Main Menu. This shall display the PID Controller sub-menu.



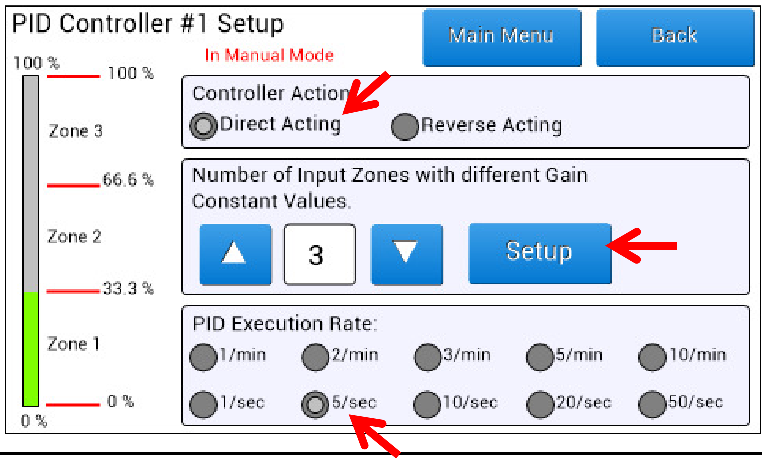
Then press the 'PID Controller Setup' icon, as shown below.



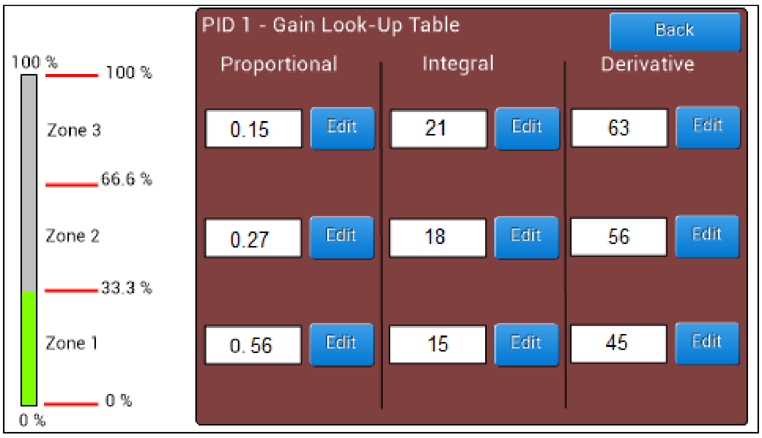
The first step is to determine whether this PID Controller is to be setup as 'Direct Acting' or 'Reverse Acting'. If the fluid level within the tank decreases below the Set-Point, the PID Controller will try to increase the level by opening the fluid inlet Control Valve further. Therefore, a positive change of PID Controller output shall cause a positive change in the process measurement, being the fluid level. Conversely, a negative change in of PID Controller output shall cause a negative change in the process measurement. Therefore, this PID Controller shall be setup as 'Direct Action', press the associated radio button as shown below.

As flow control is a fast process, the 'PID Execution Rate' shall be set for 5 execution cycles per second. Therefore, select the '5/sec' radio button as shown below.

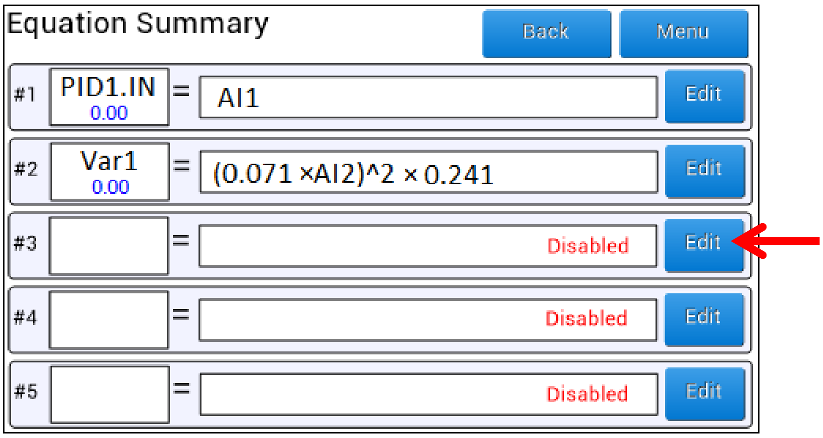
For optimal control, this PID Controller shall be setup to have 3 input Zones. This means that the Input signal range shall be divided up into 3 Zones and there shall be a different set of PID gain values for each of these zones. Press the associated up arrow button, as shown below, to create 3 Input Zones. Then press the associated 'Setup' button to display the PID gain values.



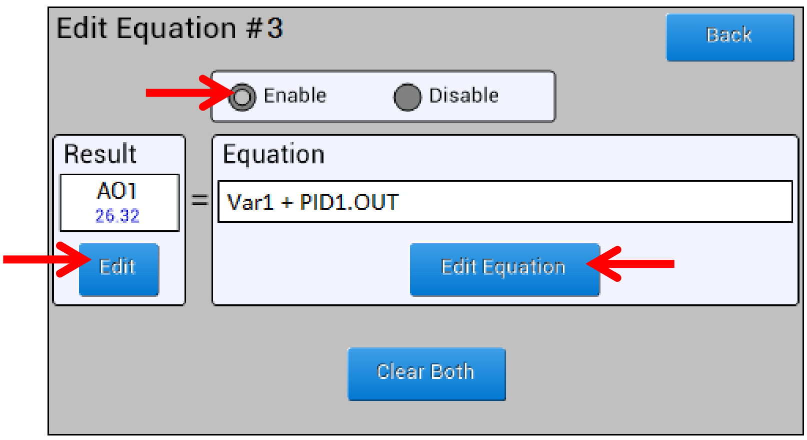
From using standard open-loop step response PID tuning practises the following PID gain values were obtains and entered in as shown below.



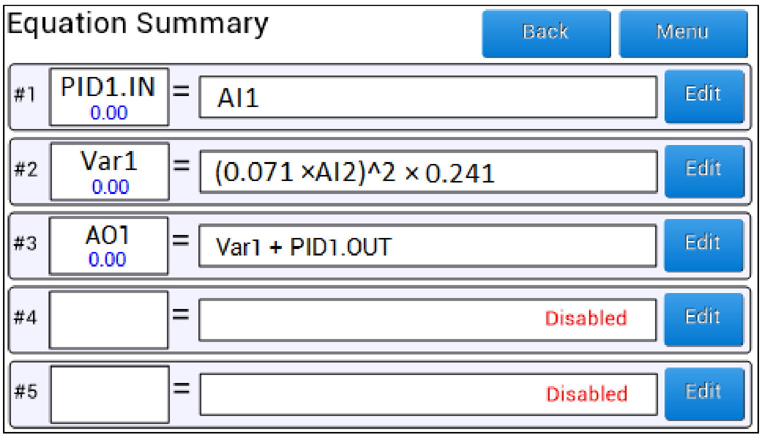
Now the Output signal from PID Controller #1 needs to be linked to the fluid inlet controller valve output channel (AO1) along with the feed-forward computation. This shall be again done with an equation. As before navigate to the 'Equation Summary'. Press the corresponding 'Edit' button for Equation #3 as shown below.



Below is the 'Edit Equations #3' screen. Press the 'Edit Equation' button and enter the "Var1 + PID1.OUT". Then press the Result's 'Edit' button and enter 'AO1' to assign the result of this equation to the Analogue Output Channel #1. Press the 'Enable' radio button to start this equation's execution. When finished press the 'Back' button.

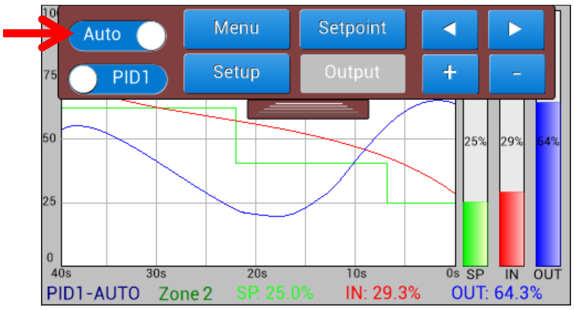


Below shows the 'Equation Summary' screen with all three equations enabled.



To start PID Controller #1 executing, it must be put into Automatic Mode. To do this press the 'Operator' icon from the Main Menu, as shown below.

From the 'Drop-Down Tab Menu', set the top left toggle switch to 'Auto' mode as shown below. PID Controller #1 shall start executing and accepting its Set-Point values from the external controller.



15.4. Conclusion

Below visually depicts what has been created.

The tank level signal is read by the AP-100 through Analogue Input Channel #1 'AI1' and assigned to the PID Controller #1 Input using Equation #1. The fluid outlet flow rate signal is read by the AP-100 through Analogue Input Channel #2 'AI2'. This signal is used within the feed-forward computation which is implemented using Equation #2.

The PID Controller #1 has been configured with 3 input zones that have appropriately tuned P, I and D gain values.

The Output signal from the PID Controller #1 and the feed-forward computation have been added together with the result assigned to 'AO1' using Equation #3.