MCW Application Notes

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Title	Optidrive E2 PI Control

Summary	This document gives information on the basic set up of the Optidrive E2 PI loop

Note: Please read in conjunction with the Optidrive E2 User Guide.

Overview

Optidrive E2 has a built-in flexible proportional-integral (PI) controller that can be used for a variety of process control applications. Typical applications include pressure control, flow rate control, temperature control etc.

This document describes the principles of PI control, the procedure for setting up the Optidrive E2 in PI mode and how to calculate the parameter values.

Principles of PI Control

Industrial applications or processes can often require a constant process value (such as pressure, flow rate, fluid levels, temperature etc.) to be maintained at the process output regardless of any variations in the system operating parameters.

For example: The pressure in a building stairwell might be required to maintain a set pressure regardless of the number of doors or windows that may be opened onto that stairwell. This can be achieved by applying a variable speed drive with PI control to vary the speed of themotor and fan controlling the stairwell pressure in order to modify the fan speed to attempt to maintain the desired pressure.

The PI system would need feedback from a sensor that represented the variable to be controlled and a set-point that represented the process level the system was required to maintain.
So for the stairwell example, we would likely require a sensor to be placed in the stairwell to feedback the level of pressure currently within the stairwell and a set-point to our drive that told the PI controller what pressure we were looking to achieve. The PI controller would then modify the

output speed of the fan until the feedback matches the set-point and try to maintain operation in this ‘balanced’ condition. If at any stage a door or window was opened that resulted in a pressure drop in the system then the PI controller would react by increasing the speed on the fan to compensate.

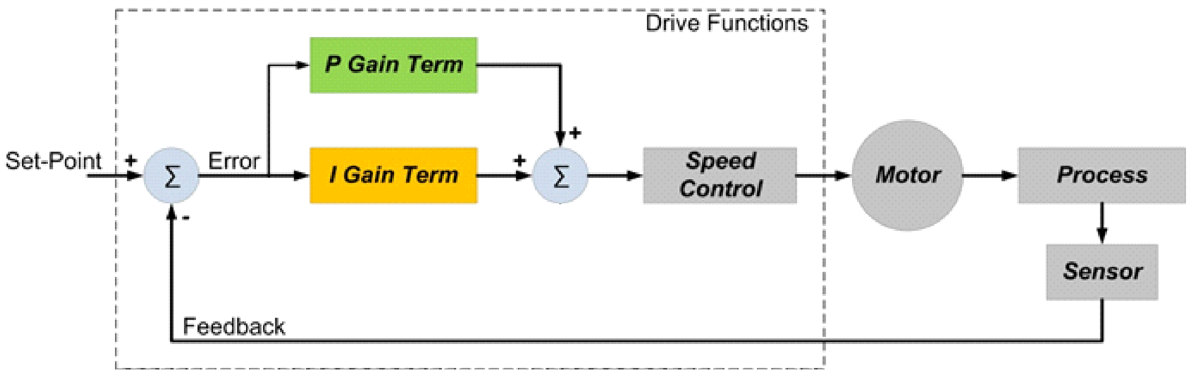
The PI controller within a variable speed drive is effectively altering the speed of the motor to try and maintain a process variable in the system. Clearly there has to be a direct link between the speed of the motor changing and the process value to be maintained changing. The sensor in the system provides feedback to the drive via an input and an input is given to the drive to tell it the level of feedback it is required to maintain.

Essentially the PI controller is operating on the "error value” or the difference between the measured process variable and the desired set-point or commanded level of operation. The drive will attempt to eliminate the error (maintain the set point) by adjusting the drive output.

How the PI controller reacts to the existence of an error is determined by the size of the error (difference between the feedback and set-point values) and the time the error has existed. The purpose of the PI controller is to, not only correct for the error, but also to allow the system to be “tuned” for best performance. Best performance generally means that the process error is corrected in the shortest possible time although this does depend on the application.

The name “PI” refers to the mathematically functions within the controller used to manipulate the response and tune the system. PI represents the terms Proportional–Integral given to the two mathematical functions that can be adjusted and each has a fundamentally different affect on the system. To successfully commission a variable speed drive it is not necessary to understand the mathematically equations behind these functions but only understand how changing them will affect the behaviour / response from the PI controller.

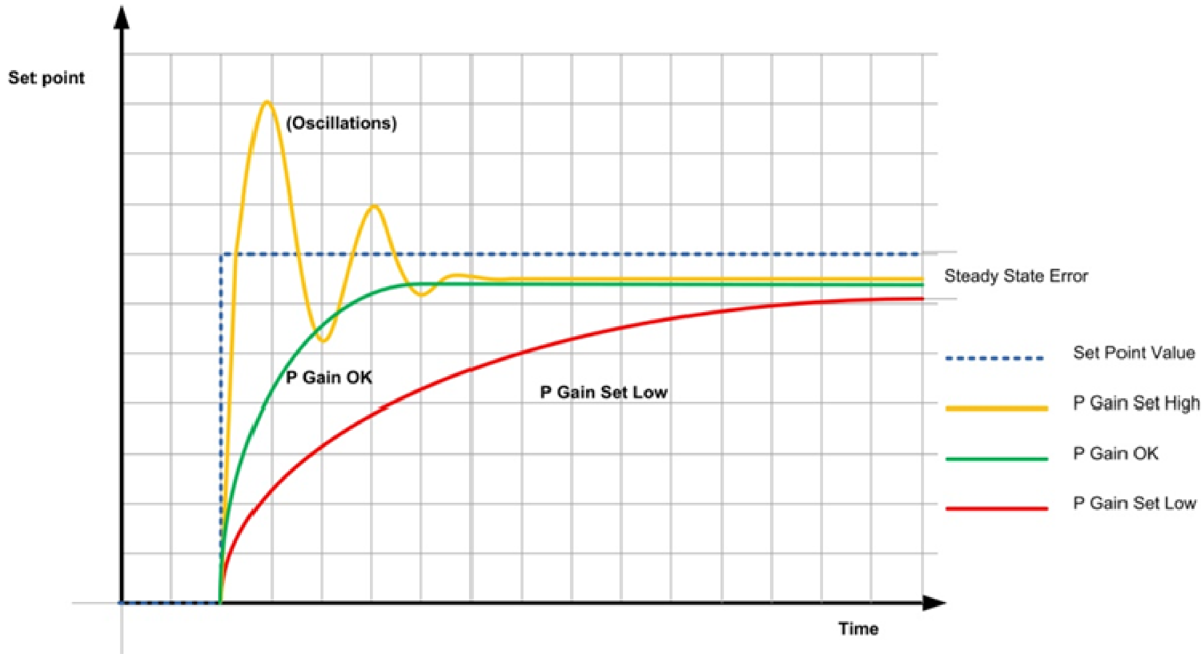
A Basic PI Control Function diagram for the Optidrive E2 is shown below:



P The proportional (P) term in a PI function is simply a multiplier for the error signal and is the easiest to understand and adjust. Hence the P term directly affects the size of the error value seen by the PI controller and how quickly the drive output responds. If the P gain value is set too low then the drive will take more time to modify its output and correct the error. If the P gain is set too high then the drive may respond too quickly and cause the system (and feedback) to overshoot the required set-point. This results in what are called 'oscillations' where the PID controller has to compensate for, or rectify, the overshoot. If the P gain is set significantly too high then the system can become 'unstable'. In an unstable condition the PI controller is unable to rectify the overshoot.

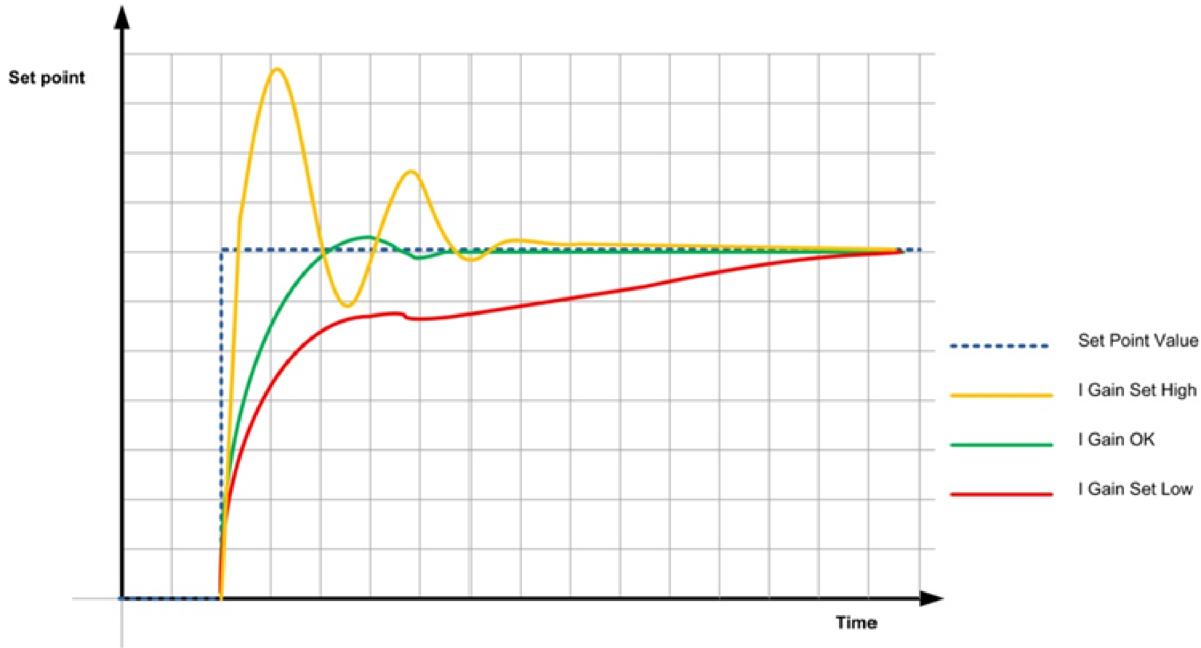
When only a P term is applied to the PI controller (no 'I' term) then there will always be error in existence between the commanded set-point and the feedback level. This error exists because the P term is a multiplier value and with nothing (no error) to multiply the output will start to decrease (in turn creating an error). The system will eventually balance out with a steady state (or consistent) error always present.

The following graph shows the affects of tuning the Proportional term:



I The Integral (I) term in a PI function samples the error present over a given time and takes an average of those values, hence the affect on the system is based on the accumulation of recent errors rather than the current or existing error. The I term is used to eliminate the steady state error (caused by only applying P term) and it adds longer term precision. The I term should always be used in conjunction with the P term.
As the I term is the error over a set time it is typically set in seconds which defines the time period that samples are accumulated. A low value of I term results in a low sample time, making the drive output more responsive but more prone to instability. A high value of I term results in a high sample time that might make the drive output unresponsive or not fully eliminate the steady state error. Small changes of Integral time can have a large affect on the system response and can very quickly lead to instability. Care should be taken in adjusting this value to ensure no instability is introduced into the system, especially resulting from a large change in error or set-point value resulting in a large error occurring.

The following graph shows the affects of tuning the Integral term (having tuned the P term):



Drive Configuration and Commissioning

The following section will explain how to configure the Optidrive E2 in PI mode for a basic application. The configuration has been broken down into smaller steps set out in the sequence that they should be followed during commissioning.
The following steps assume that the Optidrive E2 is in the default state – if parameters have been modified from their default state, this could affect the operation of the drive.

Acceleration & deceleration ramps
For Fan and pump applications, the default acceleration and deceleration ramps of 5s maybe too fast and may need to be increased. The acceleration and deceleration parameters should be set to appropriate values for the application.

P-03 = 5s – Acceleration ramp
P-04 = 5s – Deceleration ramp

Motor data
The first step is to enter the motor nameplate data into the drive as follows:
P-07 = Motor Rated Voltage
P-08 = Motor Rated Current
P-09 = Motor Rated Frequency

Enabling and configuring the PID
The PID is enabled by setting:
P-12 = 5

Extended menu access
Set P-14 = 101 to allow access to extended parameters

P-41 PI Proportional Gain
In simple terms, the PI proportional gain parameter controls how great a variation in pump speed will be seen relative to a change in pressure. If the value used is too high, the pump will continuously change speed, and the pressure will be unstable. Typically on a pump system, the factory set value of 1 will provide good performance. If the pump speed is unstable, reduce the value.

P-42 PI Integral Time Constant
The Optidrive E2 monitors the change of feedback over time to determine the average pressure and how rapidly it is changing. This time filter helps to provide smooth operation. In most cases, the factory set value of 1 second provides good operation, however the value may need to be increased on systems where the feedback level changes relatively slowly.

P-43 PI Operating Mode
This parameter allows the user to select either direct or inverse PID control, as described below:

P-43	Function	Typical application	Feedback behaviour	Motor behaviour
0	Direct mode	Pump pressure control Compressor pressure control	Signal increases	Speed decreases
			Signal decreases	Speed increases
1	Inverse mode	Condenser fan Temperature control	Signal increases	Speed increases
			Signal decreases	Speed decreases
2	Direct mode with scaling	Pump pressure control Compressor pressure control	Signal increases	Speed decreases
			Signal decreases	Speed increases
3	Inverse mode with scaling	Condenser fan Temperature control	Signal increases	Speed increases
			Signal decreases	Speed decreases

Modes 2 & 3 allow the drives display to be scaled to show the feedback value using P-40

P-44 PID Reference (set-point) Source select
The PI reference or set-point can be taken as either of the analogue inputs or simply by using a digital reference. A digital reference can be used in most applications but it is possible to use an analogue input if a variable reference is required.

P-44 = 0 : Digital reference/set point used **(P-45)**
P-44 = 1 : Analogue input 1 (terminal 6) used

P-45 PID Digital Reference (set-point) value
When **P-44 = 0**, **P-45** sets the digital reference/set point for the PID controller.
For a simple system with a fixed set-point, the value for P-45 can be calculated from the transducer range.

e.g. if a system is required to hold a constant pressure of 1.5 bar, and uses a transducer for feedback with measurement range 0 - 10 bar, the value of P-45 can be calculated as:

$$\frac{1.5\ bar\ \times 100\%}{10\ bar} = 15.0\%$$

Standby mode

The drive will switch to Standby mode if the output frequency remains at the minimum frequency/speed set in P-02 for the time set in P-48. The drive will remain in Standby mode until the PI error exceeds the level set in P-49 and the PI output exceeds the minimum frequency/speed set in P-02.

Feedback

Feedback is via one of the two analogue inputs contained within the drive standard control terminals. All values are treated as percent (%) values internally by the drive to assist in simple set up.

P-46 PID Feedback Source Select

The PID feedback can be selected from a variety of different sources:

P-46 Value	Feedback Signal	Format of the Feedback
0	Analogue input 2 (terminal 4)	0 – 100.0% of P-47 signal type selection
1	Analogue input 1 (terminal 6)	0 – 100.0% of P-16 signal type selection
2	Motor load current	0 – 100.0% of P1-08 setting
3	DC bus voltage	0 – 1000V = 0 – 100.0%
4	Analogue input 1 – analogue input 2 (differential)	0 – 100.0% of signal differential
5	Maximum (analogue input 1, analogue input 2)	0 – 100.0% of largest analogue signal

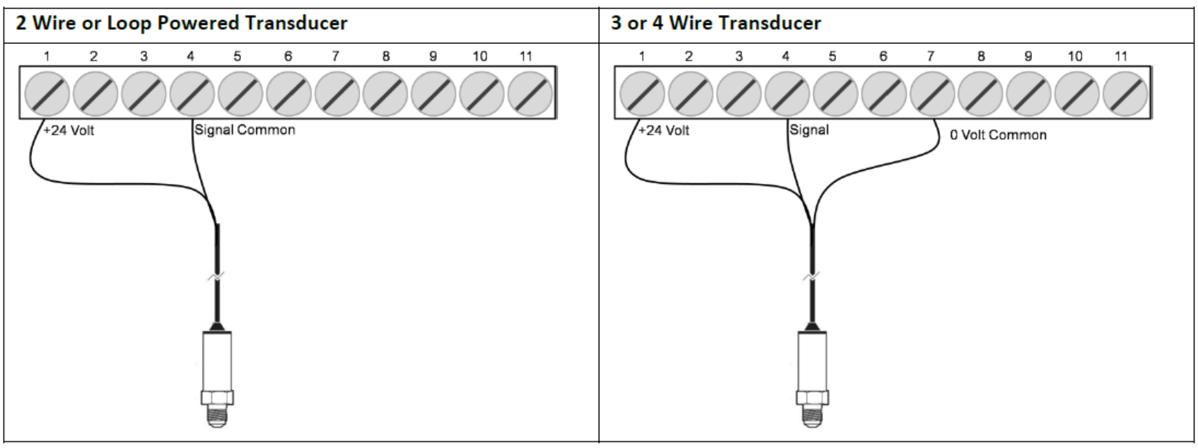
By default, the feedback signal is set to **Analogue Input 2 on terminal 4**.

The format of the feedback signal can be configured by setting the format of the analogue input as required. Most feedback transducers use the 4-20mA format.

Parameter **P-16** configures the feedback signal on analogue input 1, terminal 6.
Parameter **P-47** configures the feedback signal on analogue input 2, terminal 4.

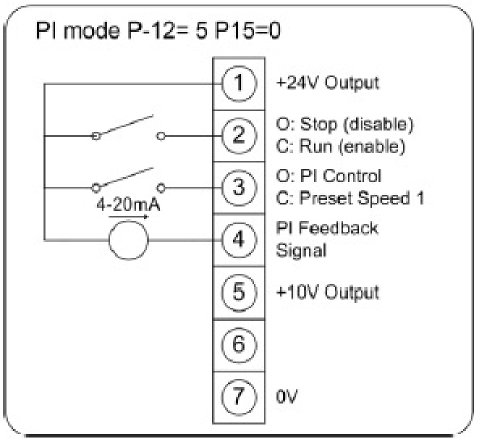
Feedback Transducers

There are generally two types of transducers, and an example of how to connect each of these to the drive is shown below. When connecting a 2-wire or 3-wire feedback transducer (e.g. 4-20mA type) as shown, check that the transducers are suitable for 24V operation.
Connect the 2-wire transducer supply to terminal 1 and the transducer output to terminal 4.
Connect the 3-wire transducer supply to terminal 1, 0V to terminal 7 or 9 and the transducer output to terminal 4.



Preparing to run the motor

So far, the drive has been configured for the motor and auto-tuned, the basic PID parameters have been set and we are almost ready to start running the application to test the operation. The feedback sensor should also be connected to the drive. Only one more control connection is required to give the run signal for the drive (considering only the absolute minimum connections). The diagram below shows an example of the connections necessary (assuming a 2-wire transducer):



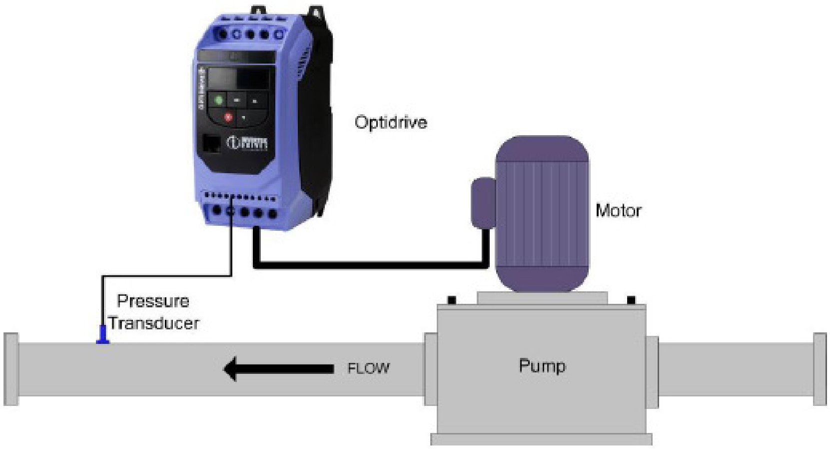
Terminal 1 = User +24V
Terminal 2 = Run / enable signal (apply 24V to run)
Terminal 4 = Analogue Input 2 (used for the feedback signal from the transducer)
Terminal 7 or 9 = User 0V Common

If the system is safe to run, we can close the switch on Terminal 2 (Run/Stop) and check first to ensure that the motor rotates in the correct direction. If the motor runs in the reverse direction then stop the drive (open the switch on T2) and power down the drive and leave for 10 minutes before swapping any two of the three output motor phases (U, V & W).

With the motor running in the correct direction the motor should start to speed up and in our example system, the pressure should start to increase up to the 1.5 bar set-point. This can be monitored on the drive display when looking at the PI Feedback Scaled Parameter.
If the load on the system drops, then the speed of the motor is also likely to reduce (assuming that direct operation has been selected) as the motor can achieve the required pressure set-point at lower speeds. Conversely, if the load increases then the motor speed should increase in an attempt to maintain the pressure set-point.
The response of the drive to any changes in the feedback can be altered by changing the PI Proportional Gain (P-41) and the PI Integral Time Constant (P-42) taking care to make only small changes to reduce the risk of an unstable system.

Note: Usually in a fan or pump application, fast responses to changes in feedback are not required. Therefore the acceleration and deceleration ramps will have more influence than the PI gains.

Application Example 1
Pressure Control – Simple Fixed PID Set-point



Example Application
Consider a pumping application.
Feedback transducer = 4-20mA / 0 – 10 bar
Pressure target level = 4 bar

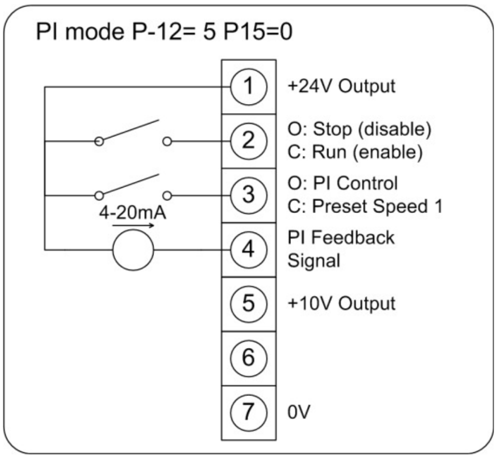
We can calculate the digital set point for as follows:
P-45 Set-point = 4 bar / 10 bar x 100.0% = 40.0%

Parameter changes required from default

Par	Function	Example Setting	Explanation
P-03	Acceleration ramp	10-30s	System Dependant
P-04	Deceleration ramp	10-30s	System Dependant
P-06	Energy Optimiser	1	Energy optimiser enabled
P-07	Motor Rated Voltage	-	Enter the values from the motor nameplate
P-08	Motor Rated Current	-	
P-09	Motor Rated Frequency	-	
P-12	Primary Command Source	5	Enables PID Control
P-14	Access Code	101	Allows Access to advanced Parameters
P-41	PID Proportional Gain	0.5 – 2	System Dependant
P-42	PID Integral Time Constant	1 – 5 seconds	System Dependant
P-44	PI set point selection	0	Digital set point
P-45	PID Digital Reference (Set-point)	40.0 %	System Dependant
P-47	2nd Analogue Input Format	4-20mA	Set to match the transducer signal type

P-33 Spin Start Software
For pump applications, P-33 Spin Start Software should be left at its default value of 0.
For fan applications, P-33 Spin Start Software should be set to a 1.
Note: Spin start software is not available on E2 size 1.

Connections



Operation

When the Run signal is given on terminal 2, the drive will enable and the motor will start to run and accelerate because the pressure in the system is low.

As the motor runs, the pressure in the system will start to increase so therefore the feedback will increase.

When the pressure goes above 4 bar, the motor speed will slow (**P-43 = 0** – direct operation)

The system will now regulate the pressure around 4 bar by speeding up and slowing down the pump as the pressure increases and decreases.

Additional settings for Standby function

It is required to enter Standby mode after 20 seconds if the pressure is maintained with no flow
Restart the pump if the pressure falls below 3.5 bar.

The simplest method to determine the minimum speed to use for Standby Mode is to slowly close the outlet flow valve from the pump after the pressure transducer. The pump should then maintain pressure on the closed system, and the no flow speed can be determined by looking at the output frequency or motor speed on the drive display. The minimum speed, P-02 should be set slightly higher than this value.

P-48 = 20.0s – Standby mode timer
P-49 - Wake Up Error = (4 Bar – 3.5 Bar) / 10 Bar x 100.0% = 5.0%

Note: When a low P Gain value (P-41) or long integral time (P-42) are used, there can be a time delay to restart the pump, as the PI output needs to climb to minimum speed. In this case, reduce the wake error level (P-49) or increase the P Gain (P-41), whilst avoiding unstable operation.

Application Example 2
Pressure control – Variable PI Set-point

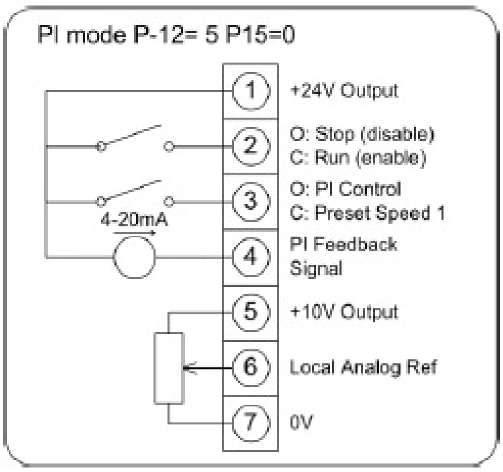
Example Application
Consider a pumping application.
Feedback transducer = 4-20mA / 0 – 10 bar
Pressure target level = variable via a potentiometer connected to terminal 6

Parameter changes required from default

Par	Function	Example Setting	Explanation
P-03	Acceleration ramp	10-30s	System Dependant
P-04	Deceleration ramp	10-30s	System Dependant
P-06	Energy Optimiser	1	Energy optimiser enabled
P-07	Motor Rated Voltage	-	Enter the values from the motor nameplate
P-08	Motor Rated Current	-	
P-09	Motor Rated Frequency	-	
P-12	Primary Command Source	5	Enables PID Control
P-14	Access Code	101	Allows Access to advanced Parameters
P-41	PID Proportional Gain	0.5 – 2	System Dependant
P-42	PID Integral Time Constant	1 – 5 seconds	System Dependant
P-44	PI set point selection	1	Analogue input 1 set point
P-47	2nd Analogue Input Format	4-20mA	Set to match the transducer signal type

P-33 Spin Start Software
For pump applications, P-33 Spin Start Software should be left at its default value of 0.
For fan applications, P-33 Spin Start Software should be set to a 1.
Note: Spin start software is not available on E2 size 1.

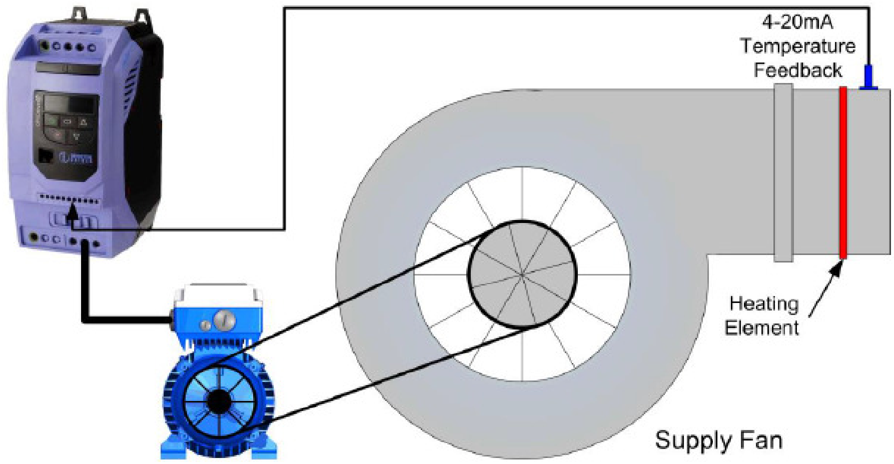
Connections



Operation

The set point can be set and adjusted by adjusting the potentiometer connected to terminal 6. The set point value can be monitored in parameter P00-01.
When the Run signal is given on terminal 2, the drive will enable and the motor will start to run and accelerate because the pressure in the system is low.
As the motor runs, the pressure in the system will start to increase so therefore the feedback will increase.
When the pressure goes above set point, the motor speed will slow (**P-43 = 0** – direct operation)
The system will now regulate the pressure around the set point by speeding up and slowing down the pump as the pressure increases and decreases.

Example 3
Temperature control using temperature feedback



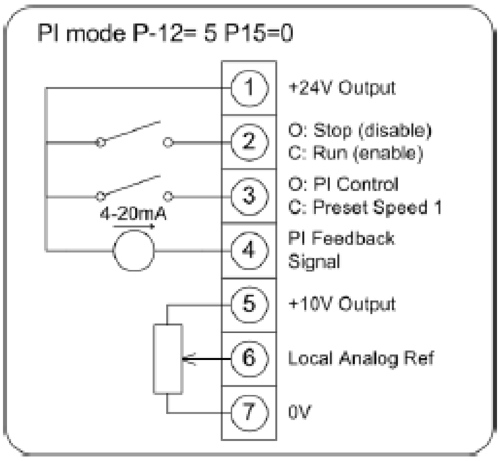
Example Application
Consider a fan application.
Feedback transducer = 4-20mA / 0-60°C
Pressure target level = variable via a potentiometer connected to terminal 6

Parameter changes required from default

Par	Function	Example Setting	Explanation
P-03	Acceleration ramp	10-30s	System Dependant
P-04	Deceleration ramp	10-30s	System Dependant
P-06	Energy Optimiser	1	Energy optimiser enabled
P-07	Motor Rated Voltage	-	Enter the values from the motor nameplate
P-08	Motor Rated Current	-	
P-09	Motor Rated Frequency	-	
P-12	Primary Command Source	5	Enables PID Control
P-14	Access Code	101	Allows Access to advanced Parameters
P-41	PID Proportional Gain	0.5 – 2	System Dependant
P-42	PID Integral Time Constant	1 – 5 seconds	System Dependant
P-43	PI mode select	1	Inverse operation
P-44	PI set point selection	1	Analogue input 1 set point
P-47	2nd Analogue Input Format	4-20mA	Set to match the transducer signal type

P-33 Spin Start Software
For pump applications, P-33 Spin Start Software should be left at its default value of 0.
For fan applications, P-33 Spin Start Software should be set to a 1.
Note: Spin start software is not available on E2 size 1.

Connections



Operation

The set point can be set and adjusted by adjusting the potentiometer connected to terminal 6. The set point value can be monitored in parameter P00-01.

When the Run signal is given on terminal 2, the drive will enable but the motor may not run because the temperature in the system is low.

As the temperature increases above the set point, the motor speed will increase (P-43 = 1 – inverse operation) to cool the system.

The system will now regulate the temperature around the set point by speeding up and slowing down the fan as the temperature increases and decreases.