APPLICATION NOTE

Product Family: **GS20 VFD**

Number: **AN-GS-021**

Subject: Tank level control PID with GS20

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Revision: **0**

Introduction

This VFD (Variable Frequency Drive) application is one of the many possibilities to use a VFD to control PV (Process Variables). This application intends to explain the use of the PID (Proportional, Integral & Derivative Actions) Loop Control. The GS20 VFD P08.XX parameter group let us set the PID loop response and operation; please see GS20 user manual at https://cdn.automationdirect.com/static/manuals/gs20m/gs20m.html. We also advise the reader to visit our web site and navigate the videos we offer for VFD and PID applications. This information will save the user many headaches when dealing for the first time with VFD and PID Loop Control.

We are briefly explaining PID Loop Control here, but there is plenty of information on the WEB to search if the user needs more in-depth knowledge.

P (Gain) is proportional to the SP's current value (SetPoint) − PV = error. For example, suppose the error is large and positive. In that case, the control output will be proportionately large and positive, taking into account the gain factor. Using proportional control alone will result in an error between the setpoint and the actual process value because it requires an error to generate the proportional response. If there is no error, there is no corrective response.

I factor accounts for past values of the SP − PV = error and integrates them overtime to produce the **I** term. For example, suppose there is a residual SP − PV error after the application of proportional control. In that case, the integral term seeks to eliminate the residual error by adding a control effect due to the error's historic cumulative value. The error, when zeroed, the integral term will cease to grow. The proportional effect diminishes as the error decreases, but the growing integral effect compensates this.

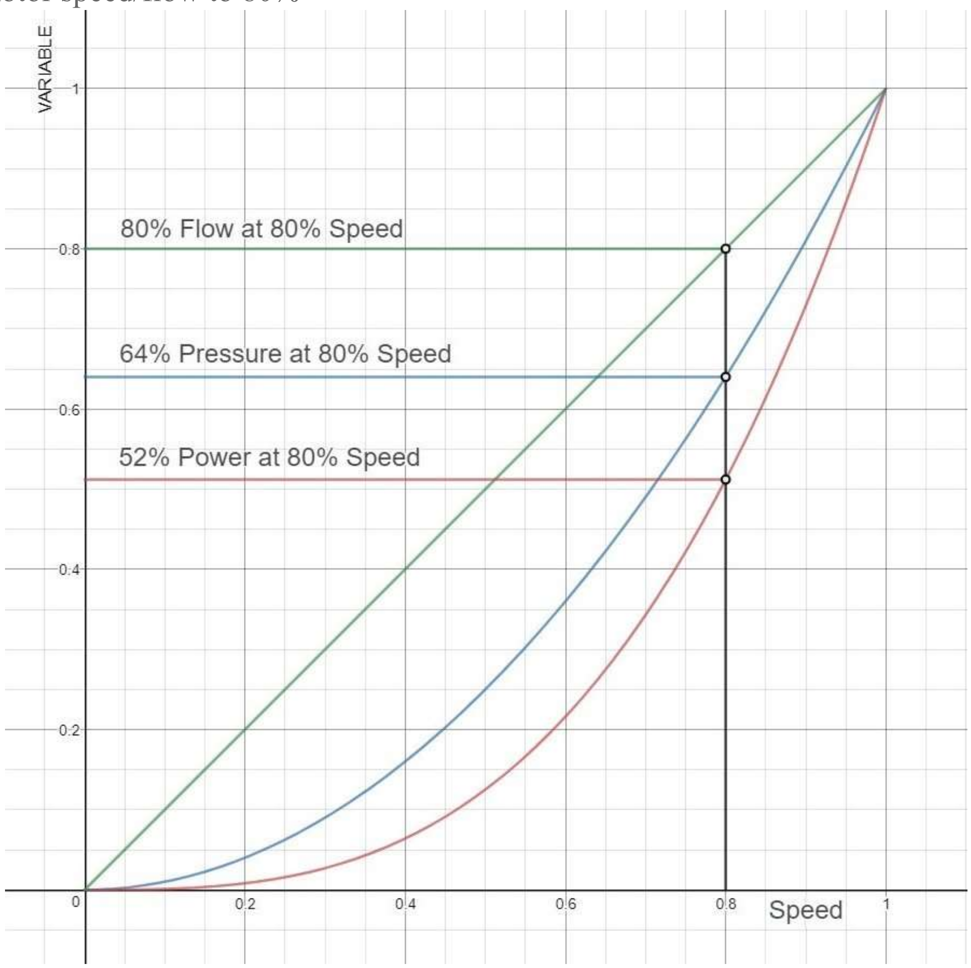
D factor is the best estimate of the SP − PV = error for future trend, based on its current change rate. **D** or "anticipatory control," as it effectively seeks to reduce the SP − PV error effect by exerting a control influence generated by the error rate change. The more rapid the transition, the greater the controlling or damping effect.

Centrifugal pump performance

When a VFD drives a centrifugal pump motor, affinity laws define how a centrifugal pump performs from 0-100% speed. When a fixed impeller is spinning at 0-100% motor speed, flow is proportional to speed, pressure is the Speed's Square, and Power is the cube of the speed.

The chart below shows at 80% motor speed, centrifugal pump flow is 80%, but the Power is 52%.

- DESIGNS – When sizing pumps, Engineers typically oversize them by >20% for various reasons.
- REQUIRES – Users typically only need <80% of the designed centrifugal pump flow capacity
- SAVINGS – Users can reduce their energy cost by 35% (1-.52/.80) by reducing motor speed/flow to 80%



On the graphic, the pump head pressure is affected by the speed, so when the pump runs at a low speed, it may not overcome the system head pressure, then the flow will manifest after the pump reaches a certain speed,

Application

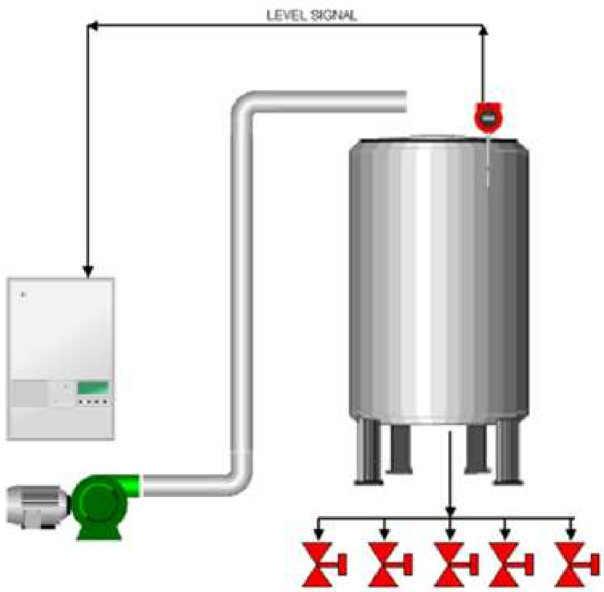
In this example, a client intends to control the water level in a tank with an ideal set point of 44 inches, being that the tank has a total height of 67 inches and an approximate volume of 500 gallons when the water level is 67 inches. The consumption of water is variable during the day and night.

The opening of up to 5 valves occurs randomly. For this exercise, each valve removes 264 gallons/minute from the tank.

For that, he intends to use a VFD to modify a pump's speed using PID control. It also uses a selector switch (local-remote) installed in a console in the control station. The pump can deliver up to 1585 GPM with a 26 feet head. Small variations in the level will not affect the outgoing flow significantly

A GS23 VFD (with PID capability) is controlling the pump speed.

The figure below shows the arrangement.



The pump flow will start around 50% of the top speed. If there is no sleep time, the pump can stay running at 50% until there is no more PID output value above 50%.

In this example, the threshold is 36 Hz or 60%.

The pump will maintain the level to compensate for the consumed water during the operation, which varies consumption based on the open valve number.

The pump size is to feed water to reach an acceptable error of up +/-4 inches. So the setpoint can be up to 48 inches or below down to 40 inches when there is more water consumption. The possible overshoot is a transitory condition and should not count.

Installation instructions and selection of enclosure & cooling not part of this application note.

External control equipment:

Part #	Description	Purpose
GCX1300	2 pos selector switch, 1 NO contact, maintained	Start VFD and motor in DI1
GCX1300	2 pos selector switch, 1 NO contact, maintained	Select local-remote in DI7
LU81-5101	Echopod level transducer	Output 4-20 mA
	Power supply for 24 VDC to supply the level transducer	

After wiring, we set the level transducer and VFD parameters

On the next pages:

- Wiring electrical diagram
- Level transducer setting.
- VFD settings.

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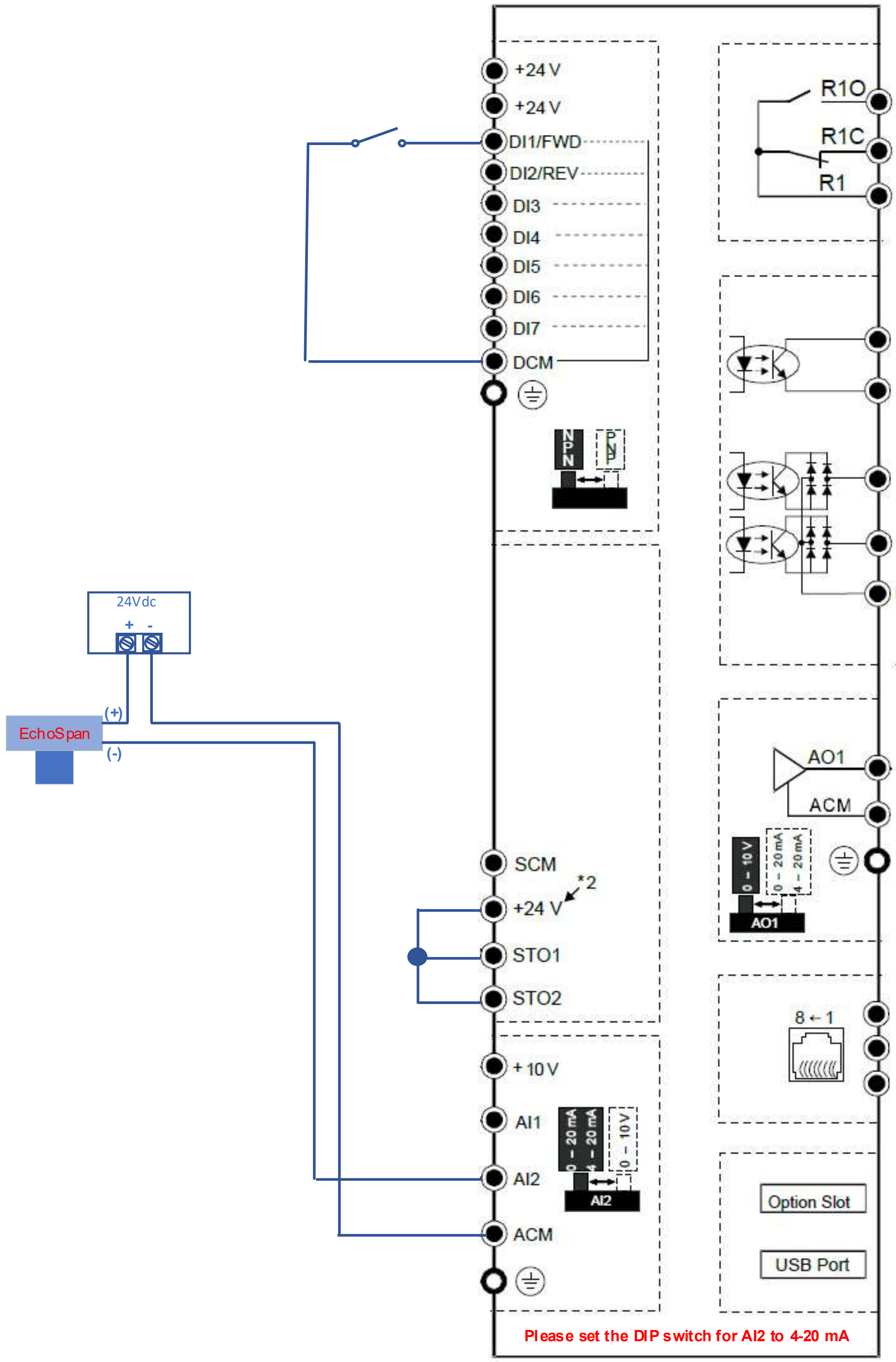
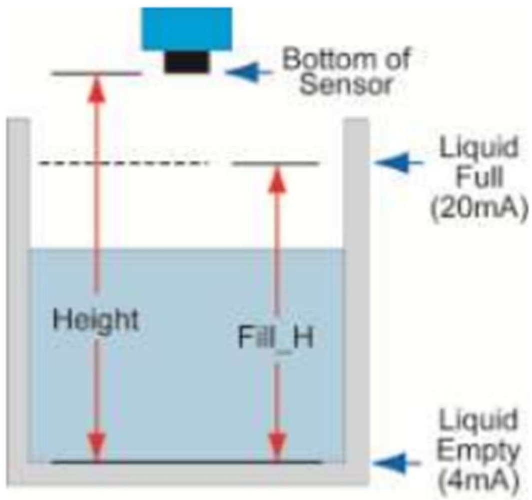




Level transducer set up
Please see user manual:
https://cdn.automationdirect.com/static/manuals/flowline/echospan_lu81_lu83_lu84_qsg.pdf
Hold on to the SELECT button for 5 seconds
1) In TOP-LEVEL MENU mode, select UNITS.
2) Next, select INCHES. SAVED will display.
3) Finally, select EXIT to return to the TOP-LEVEL MENU.
Measuring Sensor Height and Fill-Height:
• HEIGHT – Distance from the transducer face to the bottom of the tank.
• FILL-H – Maximum fill height of the liquid from the bottom of the tank.
Note: The Height and Fill Height settings also determine the 4 to 20 mA current span.
The Height setting determines the 4mA position, and the Fill-H setting determines the 20 mA position.

Set Height and Fill Height:
This setting customizes the reading for your installation. Follow these instructions to set the height and fill height for your tank:
1) In TOP-LEVEL MENU mode, select TANK.
2) Select HEIGHT.
3) Use the UP and DOWN buttons, set the HEIGHT of your tank to 67 inches (to be 20 mA)
4) To enter the value, press and hold SELECT for 2 seconds and release. SAVED will display; Now HEIGHT is set.
5) Select FILL-H.
6) Use the UP and DOWN buttons to set the HEIGHT of your tank.
7) To enter the value, press and hold SELECT for 2 seconds and release. SAVED will display. Now FILL-H is set.
8) Select EXIT to return to the TOP-LEVEL MENU.
9) Select RUN to return to Operational Mode.

GS20 set up

Wire it per the schematics in the figure on a previous page.

Before programming, reset the drive to default condition with P00-02 set to 10, with the keypad Parameter values not changed are kept as default.

Parameter settings

Parameter	Description	Value
P00-11	Speed control mode	0
Selected the simplest form of control, Volt/Hz		
P00-16	Load selection	1
Selected Variable torque load		
P00-20	Frequency reference as PID	9
The remote frequency command source is the PID controller		
P00-21	Operation command source in REMOTE	1
Remote start/stop selected as external control through terminal DI1 and DCM		
P00-22	Stop method	0
Stop method is a ramp to stop		
P00-23	Motor direction control	1
Only runs in the forward direction; Selected as reverse disabled		
P00-29	Local/remote selection	4
Selected as default		
P00-30	Freq command in LOCAL	7
Selected to control the frequency with the knob of keypad potentiometer		
P00-31	start/stop command source	0
Selected the RUN/stop keypad pushbuttons		
P01-00	Maximum operation frequency	60
Selected 60 Hz		
P01-01	Base frequency	60
Motor rated frequency		
P01-02	Motor nameplate voltage	230
Motor rated Voltage		
P01-12	Acceleration time	4.5 s
Selected to be 4.5 s in this example; this will affect the performance		
P01-13	Deceleration time	4.5 s
Selected to be 4.5 s in this example		
P02-00	Wiring for start	1
Selected to use a two-wire configuration in remote mode		
P02-07	DI7 function	56
Selected to control the remote mode here when DI7 is OFF		
P3-00	AI1 analog input selection	0
This analog input does not have a function in this example		
P3-01	AI2 analog input selection	5
*Sets the analog input AI2 for the **PID feedback** (Set signal 4-20 mA with DIP switch)*		

Parameter	**Description**	**Value**
P03-39	Keypad pot input selection	1
Selected to use the knob of the keypad potentiometer as set point frequency in LOCAL		
P05-01	Rated current of Motor	74.1 % Motor FLA 12.6A; VFD 17A
Per data on the motor nameplate		
P05-03	Rated motor speed in rpm	1755 rpm
Per data on the motor nameplate		
P06-13	Thermal relay selection	1
Selected curve to protect the motor with a fan on the shaft		
P08.00	Terminal selection of PID feedback	1
The negative feedback signal and is feeding the analog input		
P08.01	Proportional gain (P)	100
During tuning, the initial gain may change.		
P08.02	Reset value (I)	0
During tunning, the initial reset value may change. Please disable it at this time.		
P08.03	DERIVATIVE time (D)	0.00
Rate value, to be disabled always for this example		
P08.04	Upper limit of integral control	100
Initial value,		
P08.05	PID output command limit (positive limit)	100
Default value. During *tuning, it may change.*		
P08.07	PID output filter constant	0.0
The definition of this parameter is a filter constant; no filtering applied in this case		
P08.09	Feedback signal fault treatment	2
If the feedback signal is missing, the VFD will coast to stop and display a fault		
P08.20	PID mode selection	0
Select as dependent PI structure.		
P08.23	PID control flag	0
PID running in reverse maintains the motor direction		
P08.27	Accel/deceleration time for PID command	0.5
Selected to allow the output frequency ramp up or down in 0.5 s		
P08-65	PID target value source	1
Selected a fixed value of setpoint in P08.66		
P08.66	PID target value setting	65.67%
*It represents 44 inches 44/67*100*		

Now we test the VFD tested with the complete system in operation.

Check pump rotation direction; so it delivers the necessary flow for the condition of the five(5) valves opened.

Level control system tuning.

Please follow the graphs to understand the procedure:

For this example, we have connected a C-more panel to observe the control system's performance and log the process data. You can also use the Gsoft 2 scope function. But for this application note, we produced our graphs in Excel.

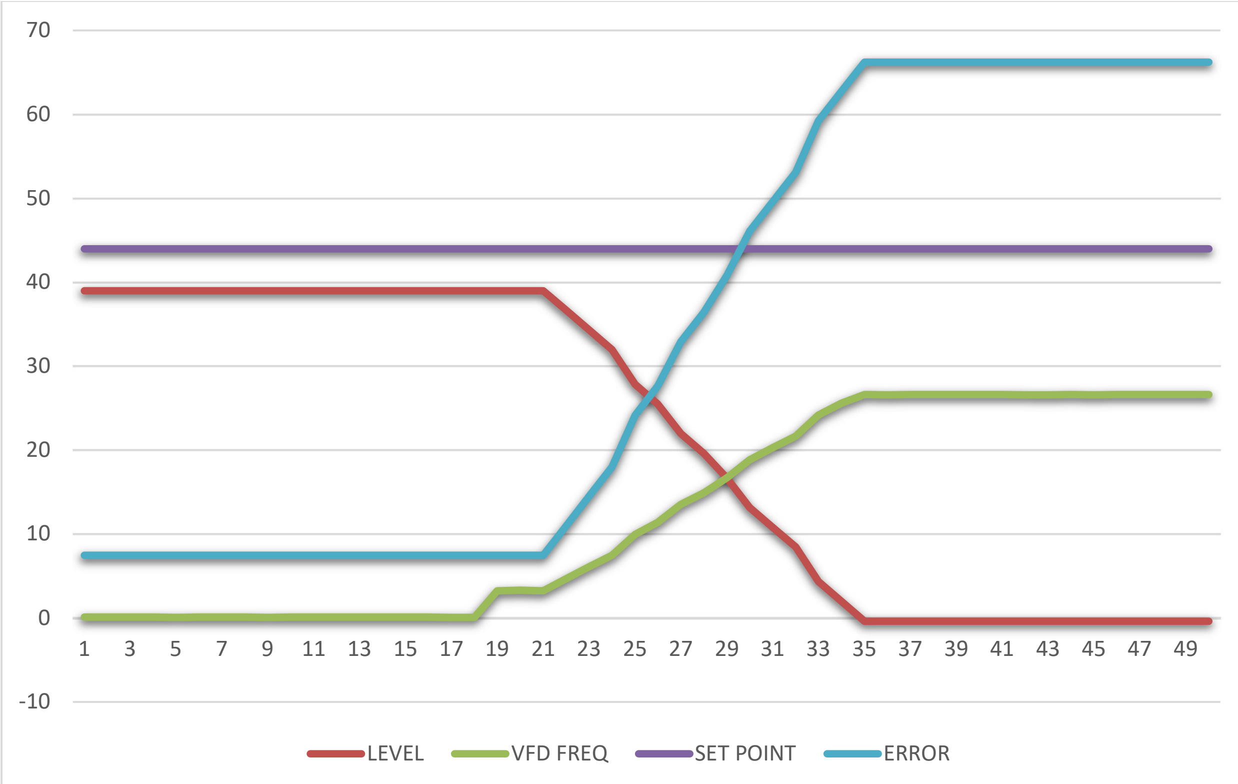
These are the basic settings of the PID loop. **Please notice that every PID loop is different, and this is valid only for this specific condition!!!**

Initial conditions:

- The tank level is 44 inches reachable using manual mode
- The pump is running and in manual mode.
- There is only one valve opened when the pump starts.
- It is shown in inches the tank level, as well as the set point.

This document does not intend to get the optimal settings but to show what is necessary to do. Every PID is different, and the user should find the best gain and reset values. You may set other parameters as well.

We start the VFD with a gain of 100, reset of 0, and a derivative value of 0. With one valve opened. Then this is what we got. Your application certainly will act differently.



There is no enough gain. The error of 66 % is significant when the output frequency got flat, about 27 Hz. The level is 0 inches when we intend to go to 44 inches!

We need to add more gain up to 300%

After a test run, when inspected the time curve, we notice the need for integral compensation. Set the gain value to 100%.

The system overshoots when opening valves. The error increased, and then the output frequency went to about 55 Hz and then decreased to keep the level close to 44 Hz.

To test the stability, we closed two valves.

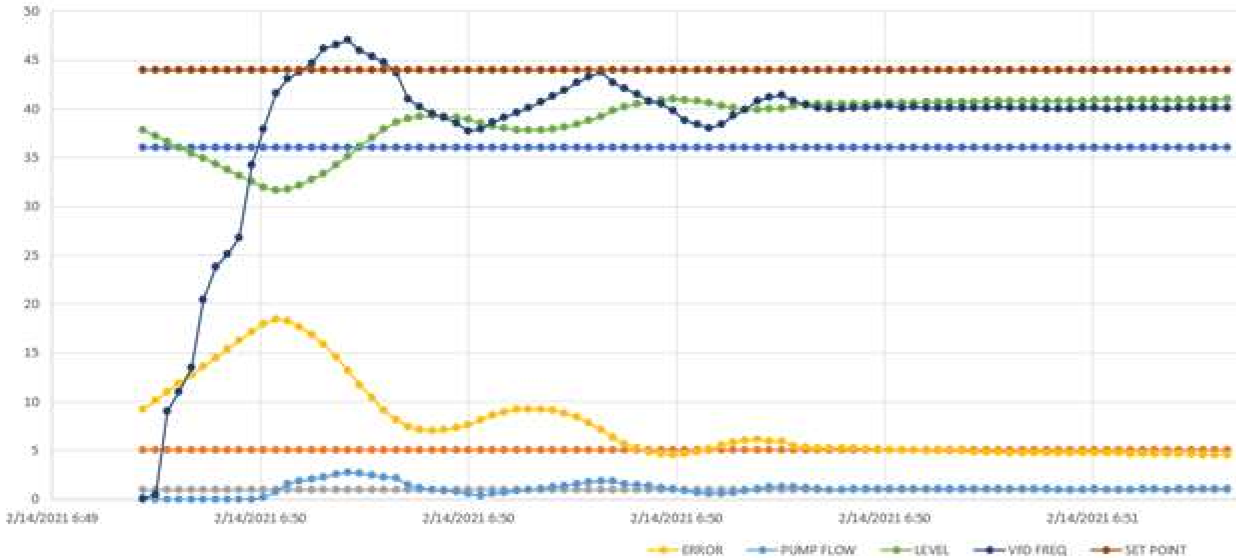
After some tuning exercise, we got the performance as shown in the following figures. There were five valves opened at this time.

Trying to find the best combination of gain, reset and rate. We observed that, in this case, the rate does not change the performance a lot. We will play only with Gain and Reset.

We did different settings to control the tank level and logging the data. We found that it is better to start with a level value close to the set point.

The gain selected seems to works better even though it is not the best.
Gain= 360
Reset = 5.0
Rate = 0

We see the trial starting to control with one open valve.



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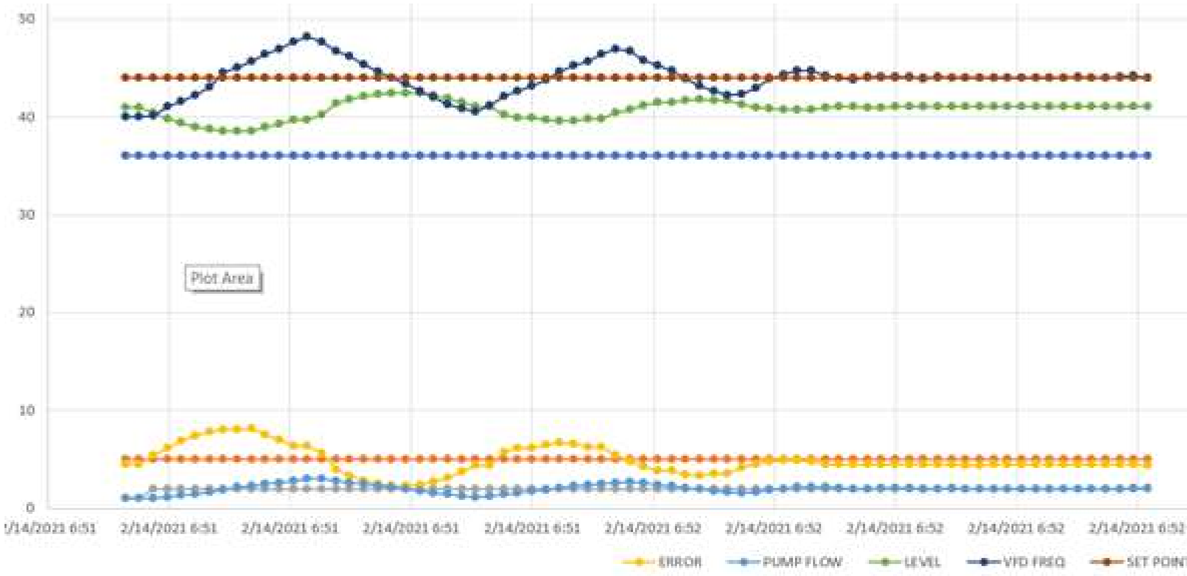
In this case, the response time to get stable is about 70 seconds, with some overshoots. Error is 4.4 %, and the tank level stables at 41.1 inches. VFD frequency is 40 Hz, and the pump flow is running,

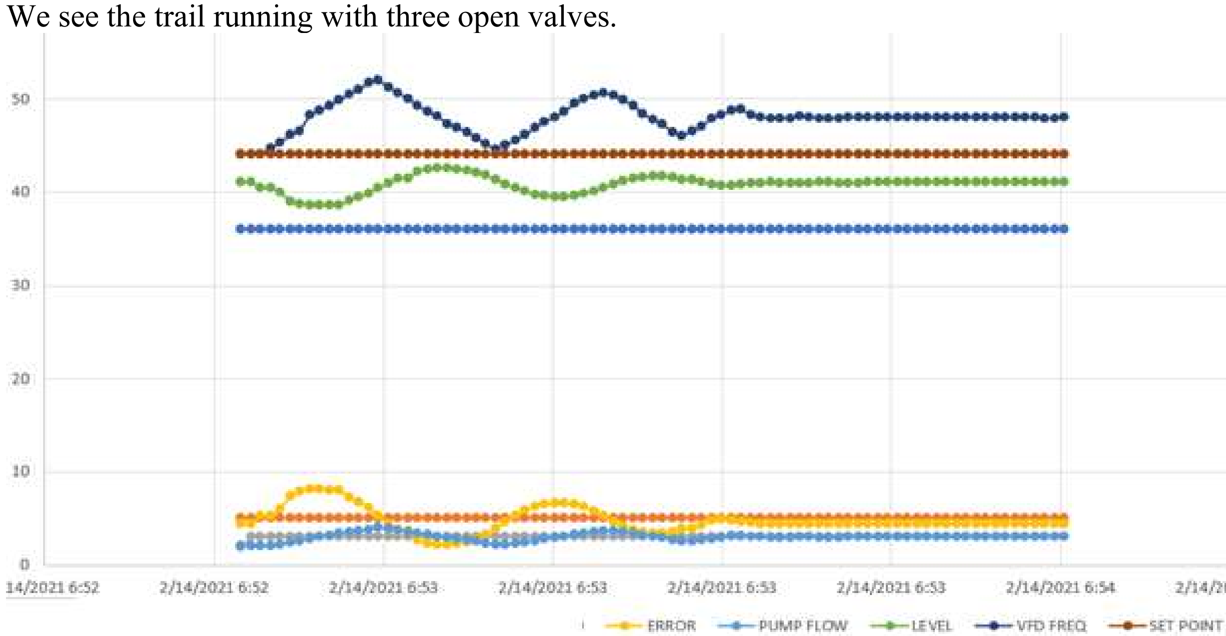
Then we will test several conditions, namely:
Opening
Two valves,
Three valves,
Four valves,
Five valves and then closing two to have three opened and then one valve opened to see if there is not instability.

We see the trail running with two open valves.



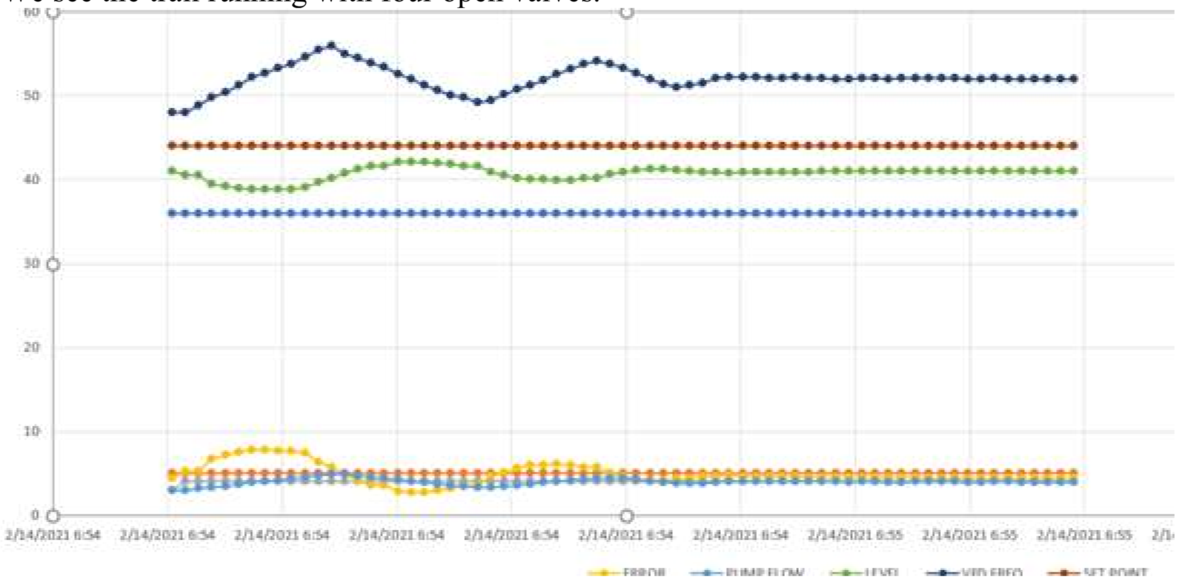
The response time to get stable is about 73 seconds, with some overshoots. Error is 4.4 % and stables the tank level at 41.1 inches. VFD frequency is 44 Hz, and the pump flow is 528 gallons/minute.

We see the trail running with three open valves.



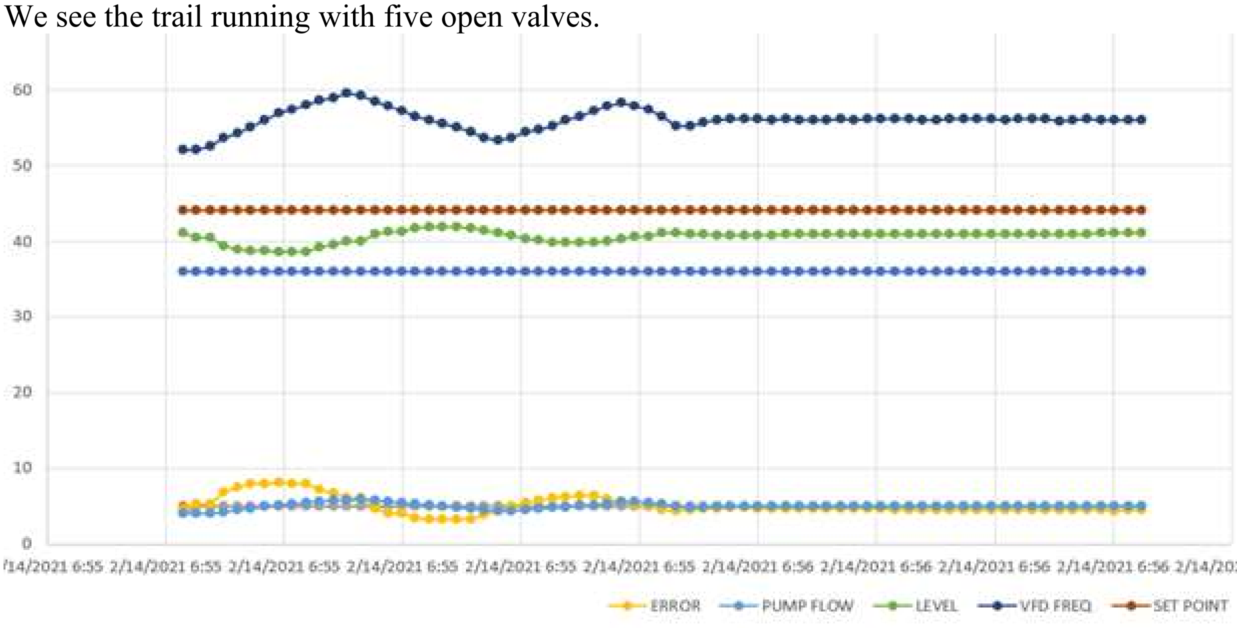
The response time to get stable is about 66 seconds, with some overshoots. Error is 4.4 %, and stables the tank level is 41.0 inches. VFD frequency is 48 Hz, and the pump flow is 792 gallons per minute.

We see the trail running with four open valves.



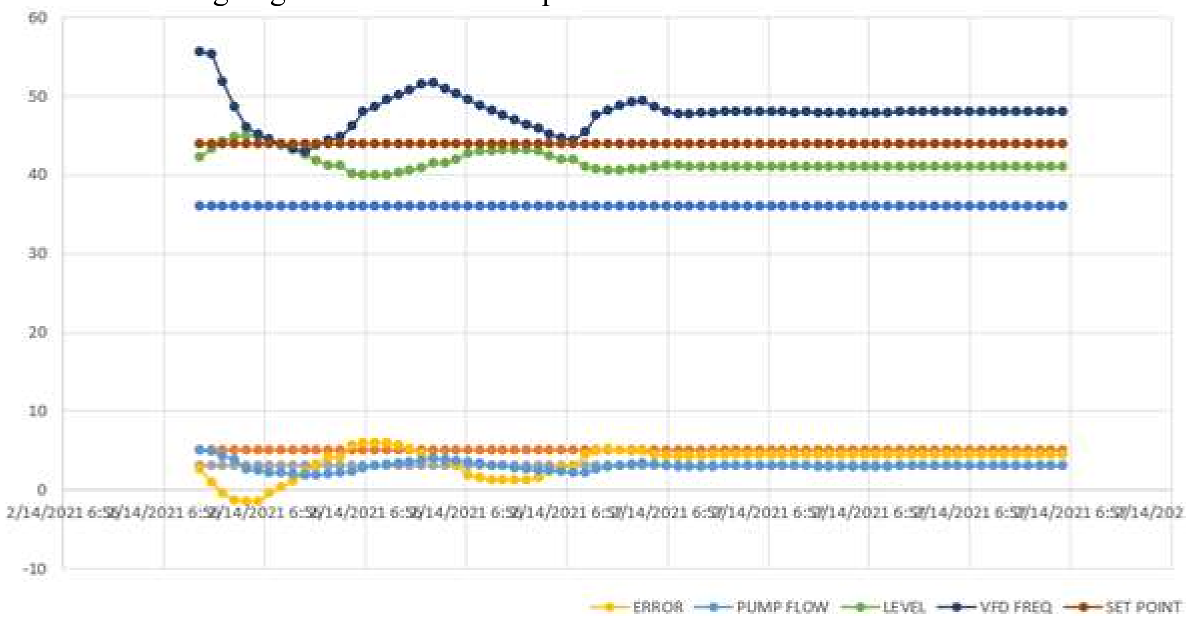
In this case, the response time to get stable is about 60 seconds, with some overshoots. Error is 4.4 % and stables the tank level at 41.0 inches. VFD frequency is 52 Hz, and the pump flow is 1056 gallons//minute.

We see the trail running with five open valves.



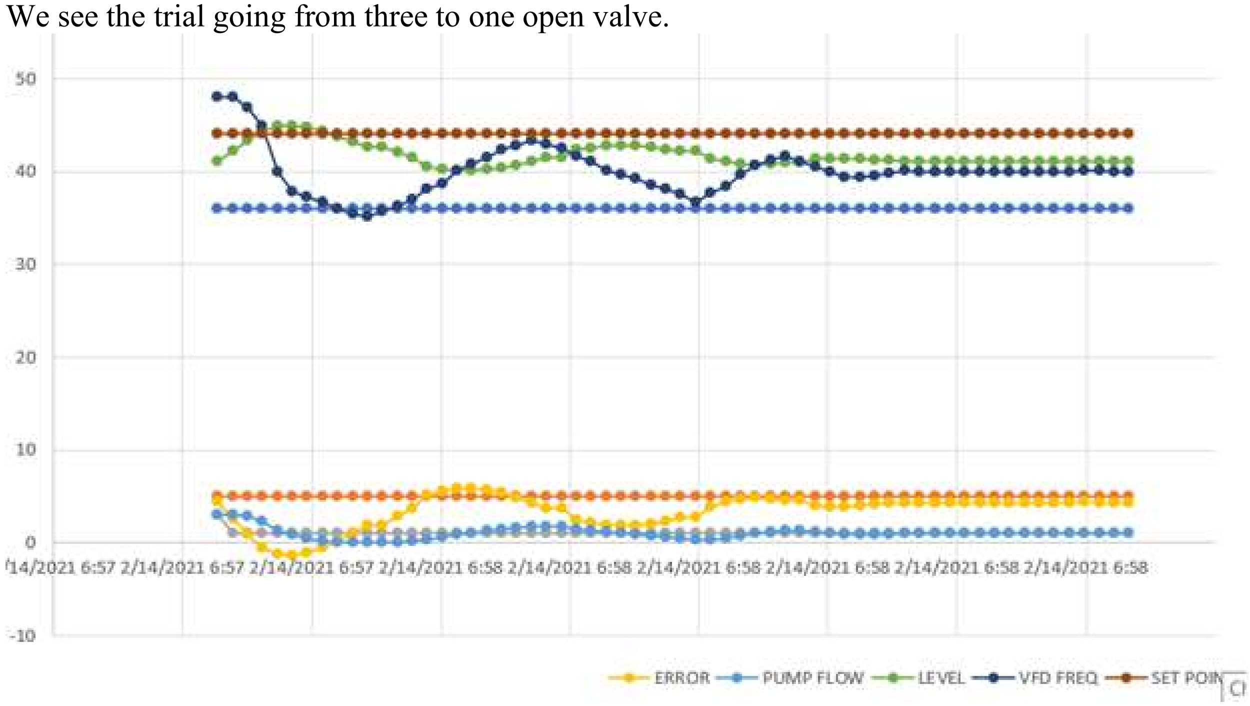
In this case, the response time to get stable is about 60 seconds, with some overshoots. Error is 4.4 % and stables the tank level at 41.0 inches. VFD frequency is 56 Hz, and the pump flow is 1320 gallons/minute.

We see the trial going from five to three open valves.



In this case, the response time to get stable is about 55 seconds, with some overshoots. Error is 4.4 % and stables the tank level at 41.0 inches. VFD frequency is 48 Hz.

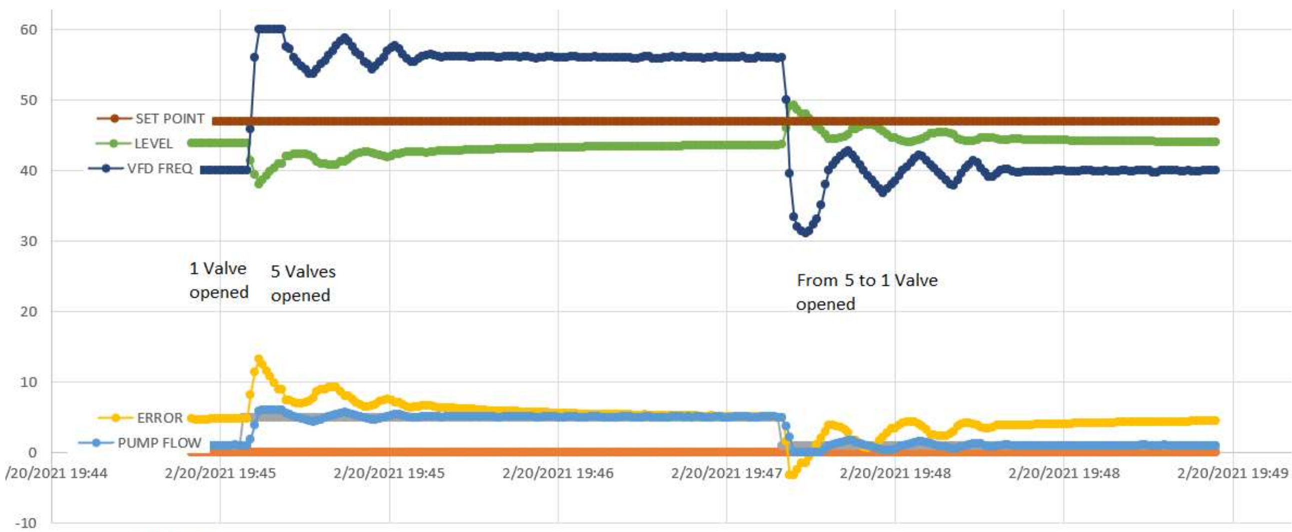
We see the trial going from three to one open valve.



In this case, the response time to get stable is about 50 seconds, with some overshoots. Error is 4.4 %, and stables the tank level at 41.0 inches. VFD frequency is 40 Hz.

Conclusions:

a) Controlling the tank level to perfection is an impossible quest since the variable consumption makes the pump rotate to compensate for the outgoing flow.
b) The control system tries to maintain the level constant.
c) The pump flow probably has to be increased to about 1.5 times the maximum outgoing flow
d) The initial premise to keep the error of +/- 5 inches was possible. With five valves, the level went to 41.0 inches to the stable of the tank level.
e) Forty-four (44) inches is the ideal tank level, not an easy task; the solution is to increase the setpoint to about 47 inches. The next figure shows the performance with five valves opened.



Gain 500, factor I - 7.0

Note that if there are no valves opened, the VFD will tend to lower the frequency and the pump will not generate any flow. To avoid that the motor run in this condition, the VFD has a feature of sleep and wakeup action.

Then it is time to add the sleep and wake-up action for the case that all the valves are closed.

The settings to be done in this example are:
P08.10 = 35 Hz The sleep frequency
P08.11 = 37 Hz The wake-up frequency
P08-12 = 30 s Sleep delay time
P08.18 = 0 Sleep mode function
P08.22 = 5 s The wake-up delay time

Please see the result in the line trend graph of the following figure, starting with one valve. At 9:48 AM, when the level is stable, all the valves are closed.
The system opens three valves at 9:49 AM, and then the VFD applies the correction accordingly.