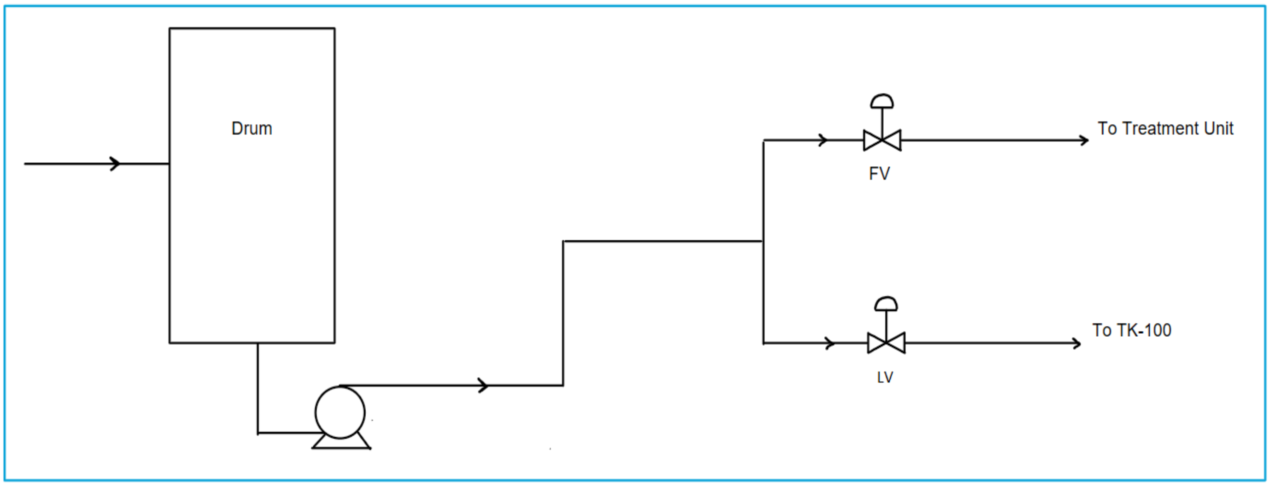
Advanced Control

Split-Range

Example 1:

Blow-down, oily water, water containing ions are always problematic to most process engineers or process plant technical managers. Therefore, before putting the unit in operation, one should take into account all aspects. Here is one example to see how most petrochemicals and process plants deals with the problem.

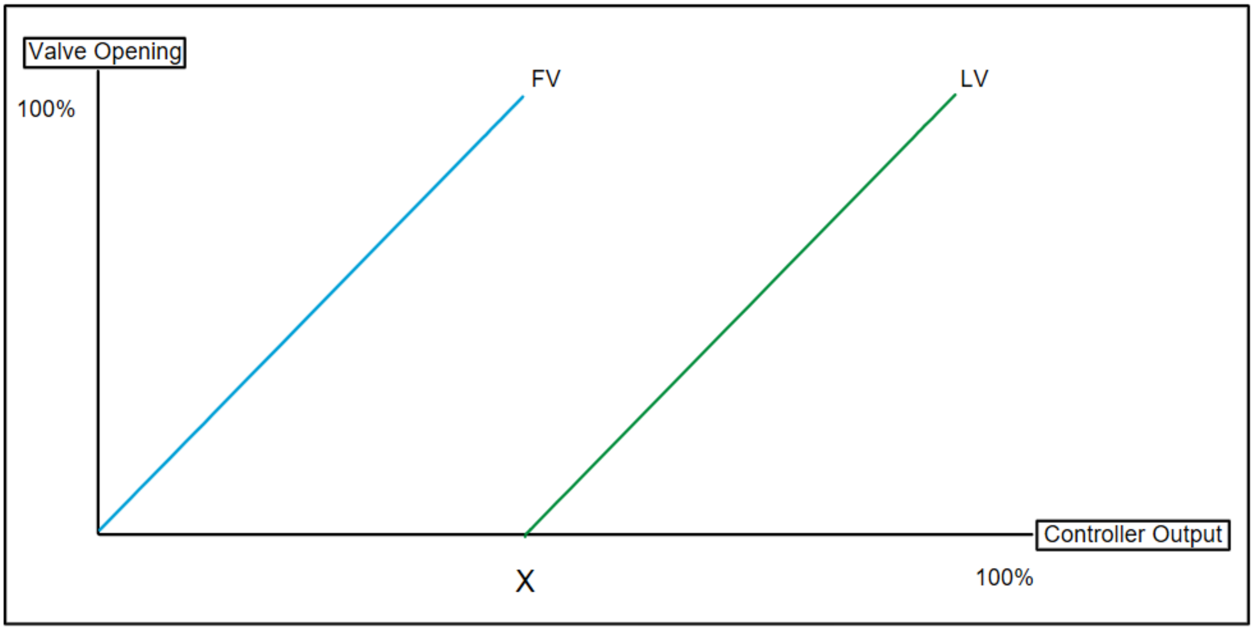


Simply the blow-down is sent to a treatment facility outside of the plant. Based on PFD-like sketch, the flow to treatment unit is controlled via FV while the flow to TK-100 is controlled by LV. Sometimes the treatment unit is out of service for say half a day and thus, cannot receive the blow-down. Therefore, the process designer should foresee a storage tank to overcome such operational problems in the future.

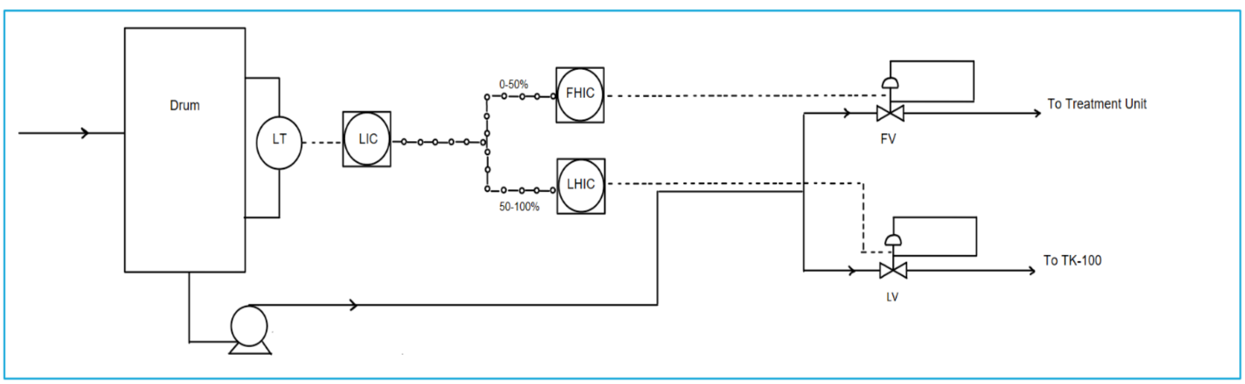
Let’s view the process from another perspective. There is a surge of blow-downs because of an emergency. Imagine yourself as the controller; you open FV as much as you can but still the level in the drum is increasing. Then you as controller start opening LV and sending a part of blow-down to the tank to mitigate the problem. If we want to show the behavior of control valves on a diagram, it would be like next-page:

Just look at it. Now you can see that the controller has devided the role between the control valves. In other words, the controller has split the role between the control valves, or we professionals say, the controller splits the range of actions on control valves. That is why it is called split-range control.

The typical value of X when we have two control valves is 50% in output. So far we know that we need a LIC to control the level. We also have gained this understanding that a simple LIC is meaningless here and split-range should be used. How simple it is, right?



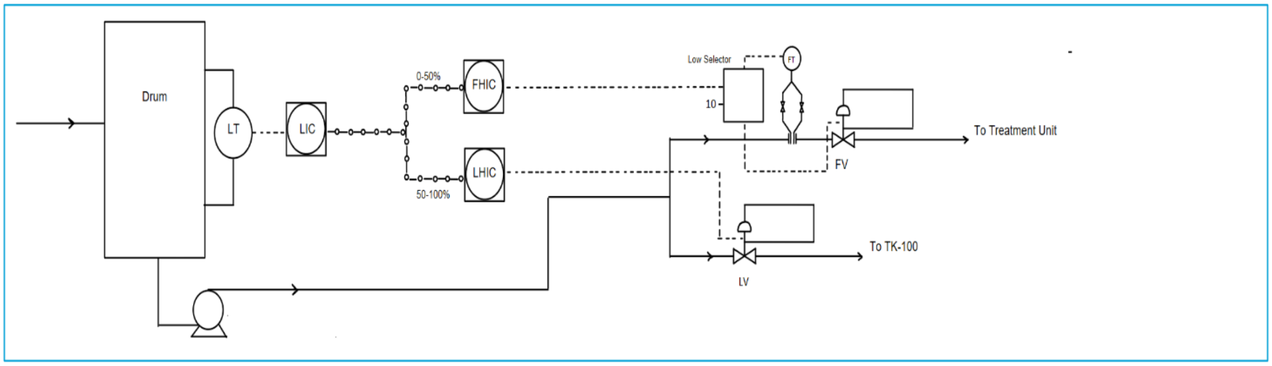
Now let's complete the PFD-like sketch by incorporating the control system.



Now there is this specification issued by the treatment facility that you can't send whatever you want when we are in operation. Our facility supports other plants as well. Therefore, you can send maximum 10 ton/hr.

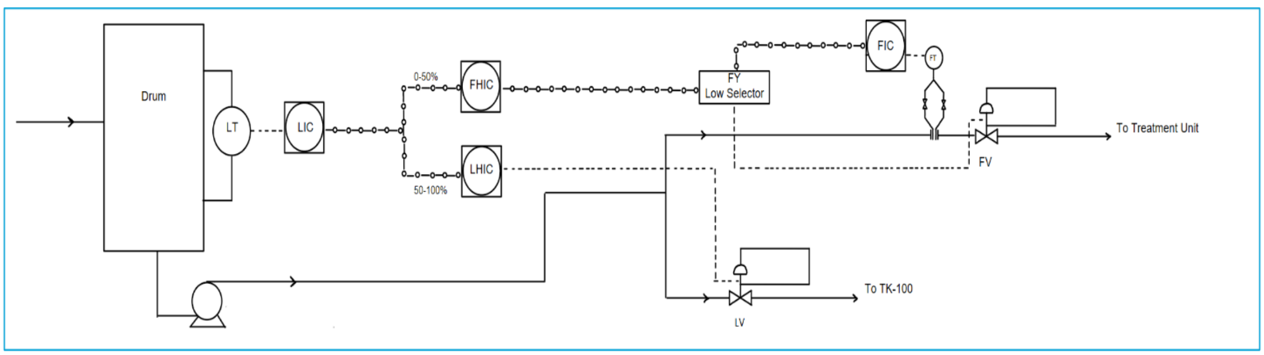
If you are thinking that we should change the design of the controllers, you are wrong since we need the controller to be split-range. Probably we should add something!

How about this, adding a block which receives the actual flowrate and compare it with 10ton/hr. If the flowrate is lower than 10ton/hr. then send the value issued by FHIC but if the value is more than 10ton/hr. then select the 10ton/hr. In fact, we want to give the block the name, it would be low selector since it always selects the lower value. So, the sketch would be like this:

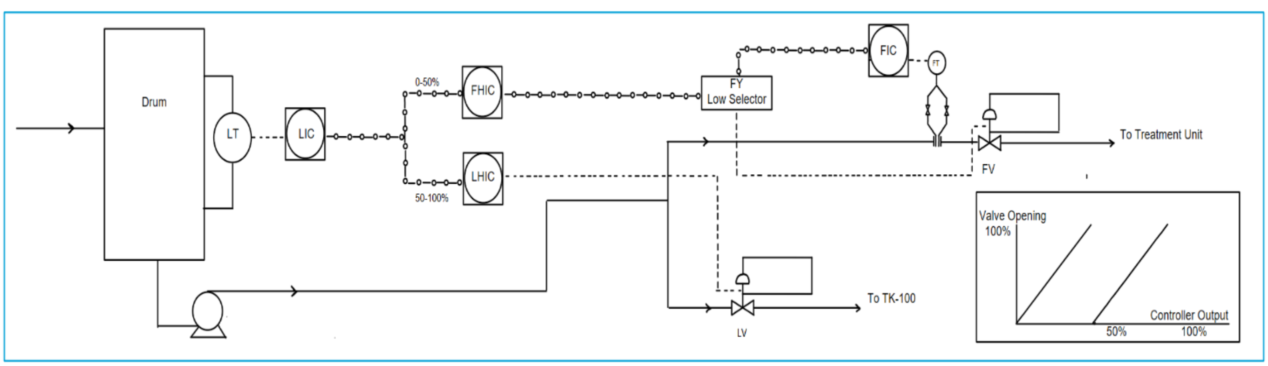


Notice: One of the inputs to the low selector is MV% while the other one is barg which can not be compared. We already know that. So don't think we have made a mistake. Just follow the chain of our perspective.

Now when we specify that we have a low selector block, it means that only instrumentation engineers have access to the calculation behind the block. So, we have to design it in a way that operation supervisor can have access to change 10ton/hr. in case the treatment facility stipulates that today the maximum flowrate which can be sent is 6ton/hr. To address the problem, we propose adding another FIC by means of which the operator can change the set point.

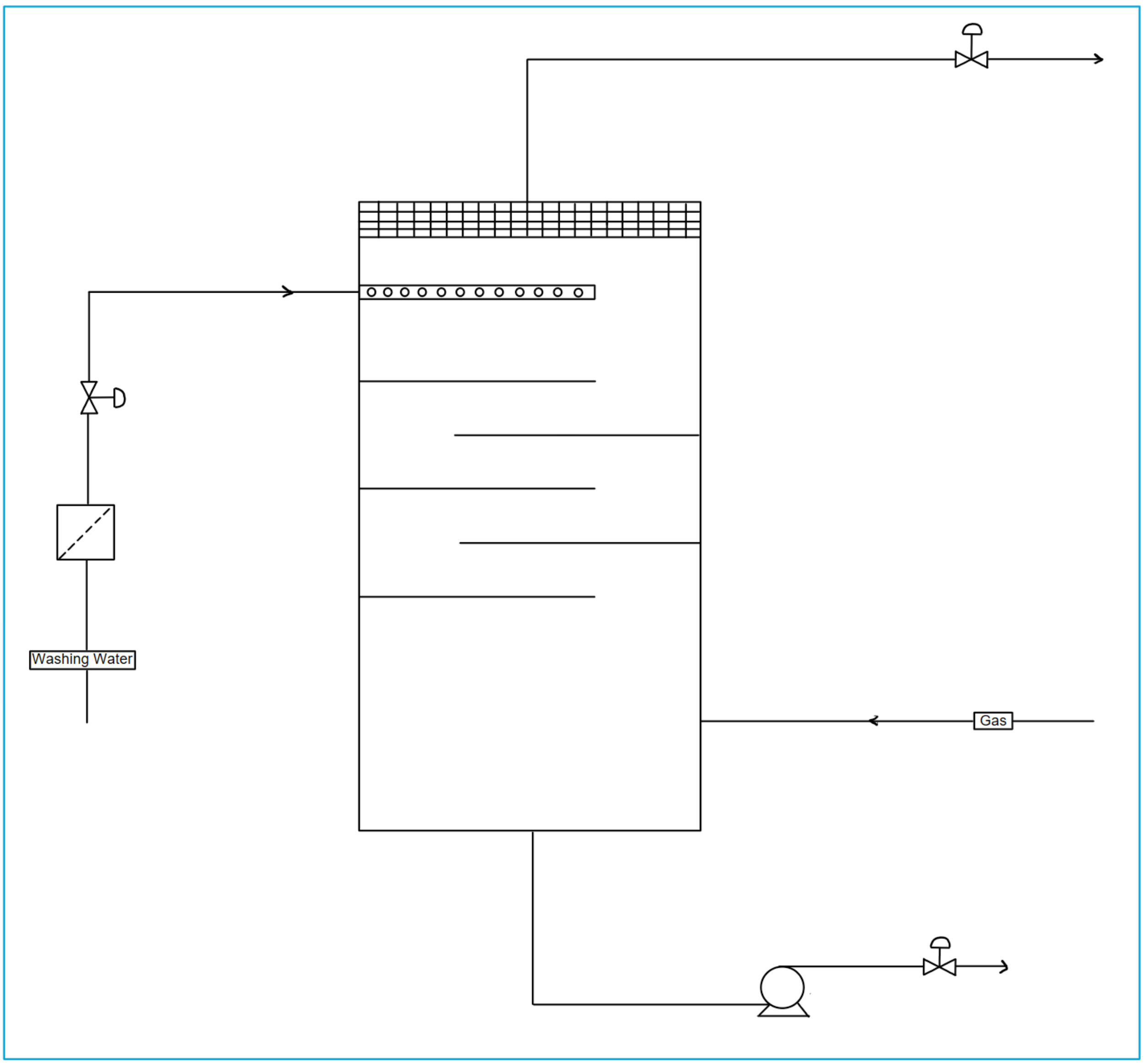


Now let's finalize it!

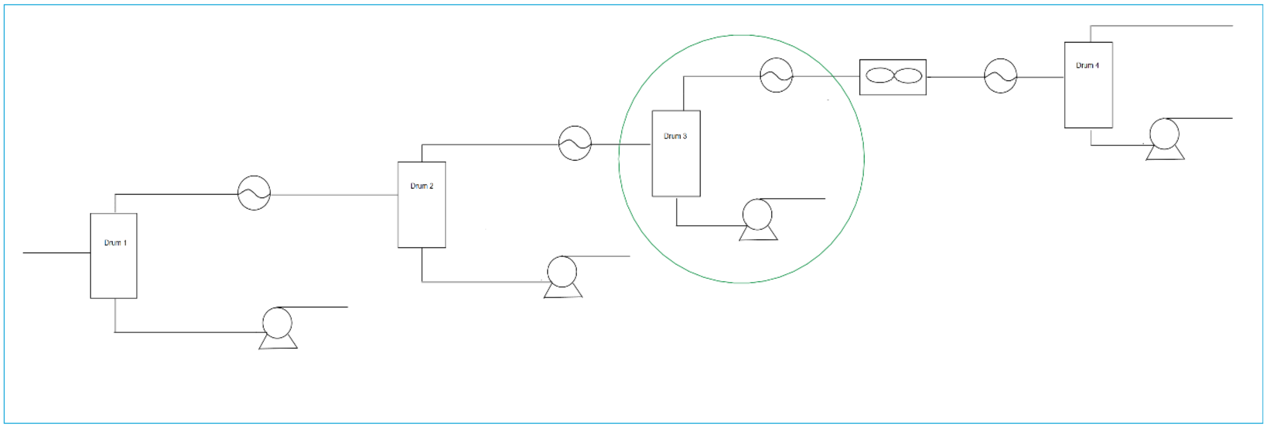


Yes, we have to show the plot in the note section of the P&ID.

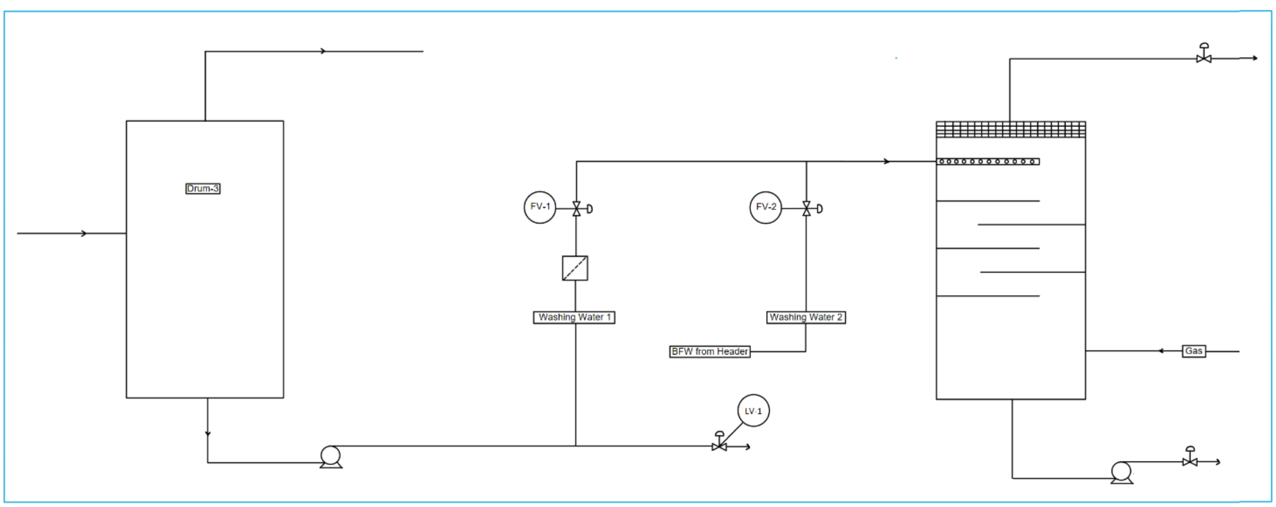
Example 2:
Catalysts are the heart of all processes. In fact, without them, literally all processes are meaningless. So, we should really take care of them during design and operation stages. Some catalysts such as reforming catalysts in hydrogen plants are extremely sensitive to some ions like Na^+. In this regard, to prevent carryover of such poisonous ions to the downstream catalysts, we can have a small drum-like tower in which countercurrent process happens. The gas comes from lower part and moves up while the washing water enters from upper part and goes downward. Based on simulation, mass and heat transfer principles, a good portion of Na^+ could move to the liquid phase. Here is the PFD-like sketch.



Due to surpless amount of process water and its quality and temperature, it could be used as washing water. But what is this process water?? Do you remember the following sketch when we where discussing the simple control loop?

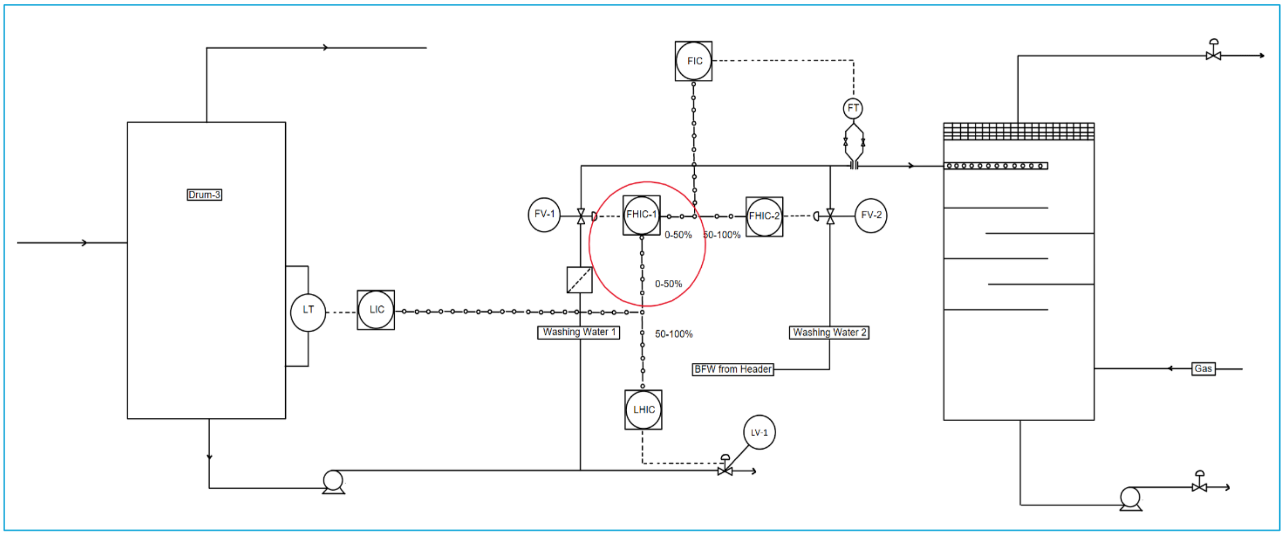


You were supposed to develop a control system for one of these drums. Anyway, let's focus on Drum 3 and re-use its separated water as its water condition approximately matches the quality of washing water. To make sure the drum-like tower operates extremely well at all conditions, BFW could be used as "stand-by" water in case some turbulences occur on Drum-3 during its operation. By the way, a part of Drum-3 separated water is also utilized in other process which needs water with such condition. To better understand what we are talking about, let's have all of them together and start analyzing its control system.



The aim here is to always maintain and keep washing water flowrate within the range. So we need a FIC for this purpose; it is also crystal clear that we should have split-range control since the controller should operate two control valves.

That is right that the flowrate of washing water to drum-like tower is very important but it should not be construed that we should ignore the separator! That is also a part of the process and should be as important as washing water flowrate in the eyes of process control specialists. Anyway, for the level control, we should also apply the split-range control since two control valves can impact the separator level.



Everything is in order except the FHIC controller part, which is shared by both Master controllers FIC and LIC. It is abnormal that the controller receives two MV at the same time; it is meaningless and the controller becomes confused which MV to take.

To overcome the issue, let's have a look at it from our process demand. To better understand what by process demand is meant, the following scenarios are provided:

Imagine Master FIC sends a MV of 40%; it means that the FV-1 opening to be 80%. At the same time the Master LIC send a MV of 20%; it means that the FV-1 opening to be 40%. Now one of these MVs should be selected. Imagining incorporation of a high selector for a FHIC-1. Let's see the result and consequences.

Scenario A: Adding a high selector before FHIC-1

Assumption: FV-1 current opening is 50%.

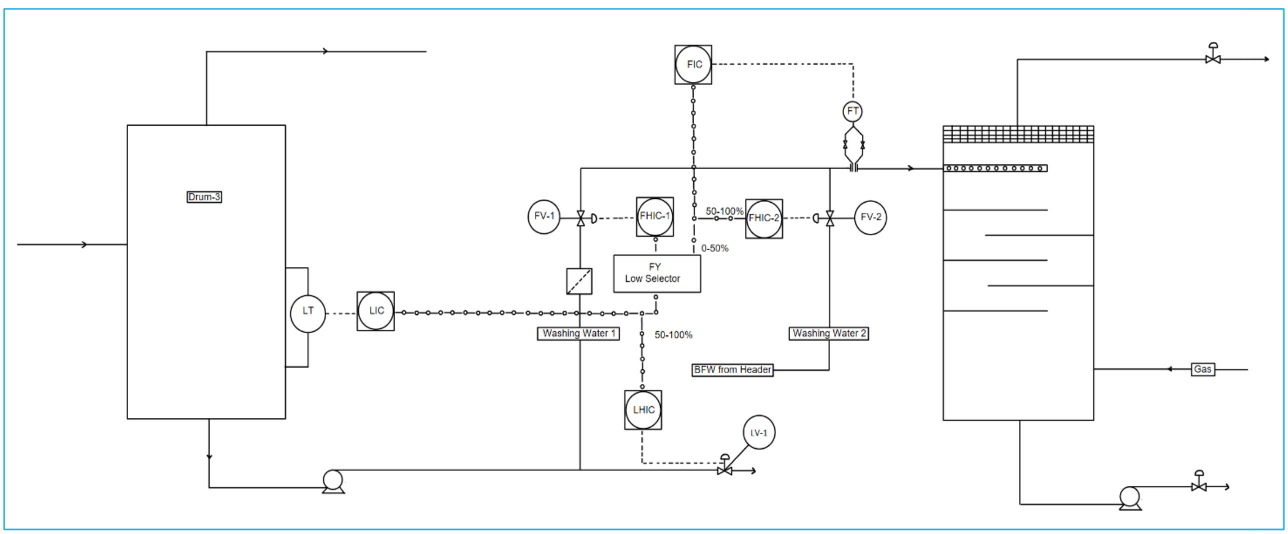
The high selector chooses 80% as the opening of FV-1 and FV-1 starts opening more and more until its opening reaches 80%. Simultaneously, since the valve opening increases, more water passes though FV-1 and the level starts decreasing. You know why? Because if wanted to keep the level within the range, the opening of the FV-1 should have been kept at 40%. The level decreases and decreases and at the same time the MV of Master LIC also decreases to 0% but its voice is going to be unheard!! Thanks to the fact that we have incorporated a high selector in our design and it is always going to choose a higher value. Finally, the separator reaches a low value and interlock is activated, stopping pumps.

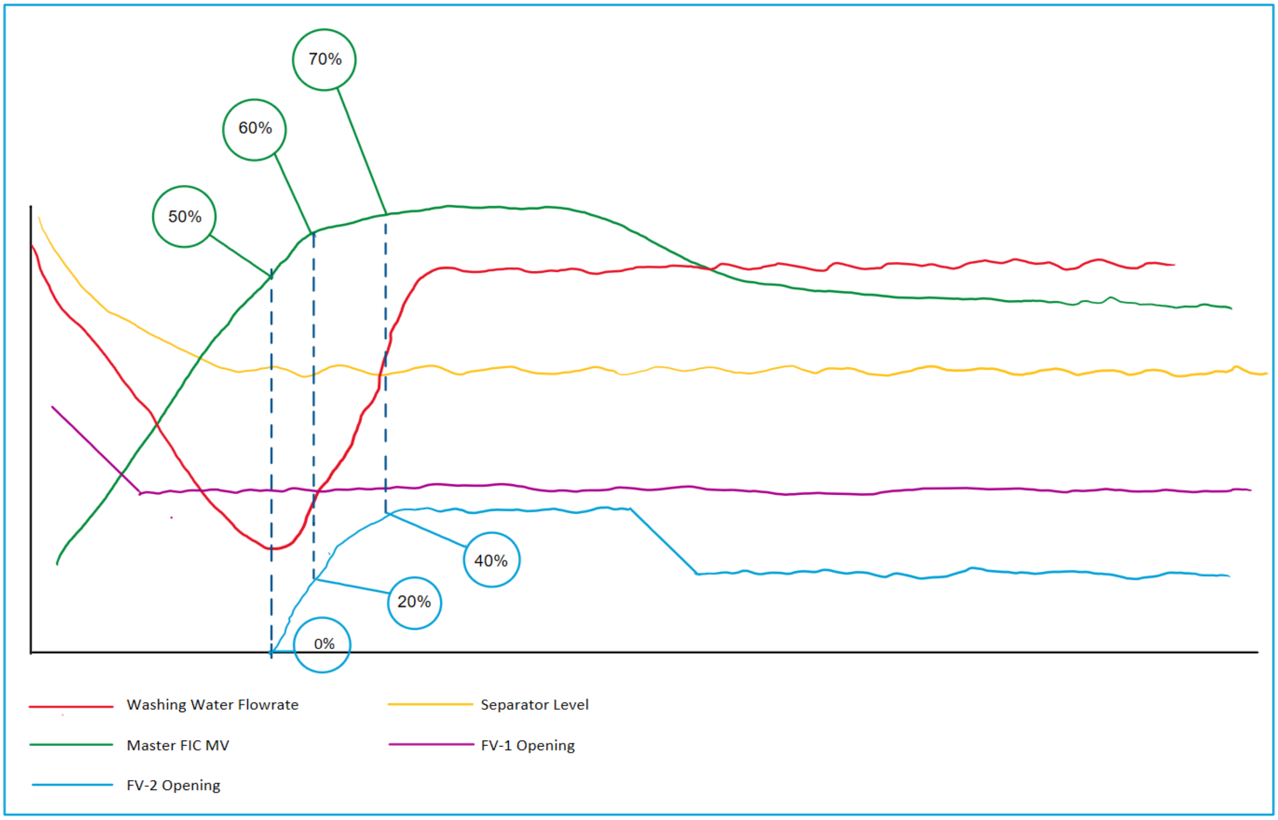
Scenario B: Adding a low selector before FHIC-1

Assumption: FV-1 current opening is 50%.

The low selector chooses 40% as the opening of FV-1 and FV-1 starts closing more and more until its opening reaches 40%. Simultaneously, since the valve opening decreases, less water passes though FV-1 and the level starts increasing. Now it sounds that the Master FIC has been ignored. So the Master FIC starts increasing its voices by increasing MV to 50%. Still ignored! Then it starts increasing its MV to 60%, which means the FV-2 opening to be 20% and start consumption of BFW. Let's think dynamic! Then the Master FIC again increases its MV to 70% and as a result, the FV-2 opening increases to 40% and more BFW passes and added to the drum-like tower. Now the thirst of the Master FIC has been quenched and the Master FIC starts decreasing its MV to 60% and stay at this value. Therefore, the FV-2 opening would be kept at 20%. After half an hour, the operation team eliminate the cause that contributed to such turbulence and the Master FIC MV goes down to below 50% and FV-2 starts closing. That is the aim in fact. We don't want to use BFW in continuously and it should be used only in turbulent situations like this.

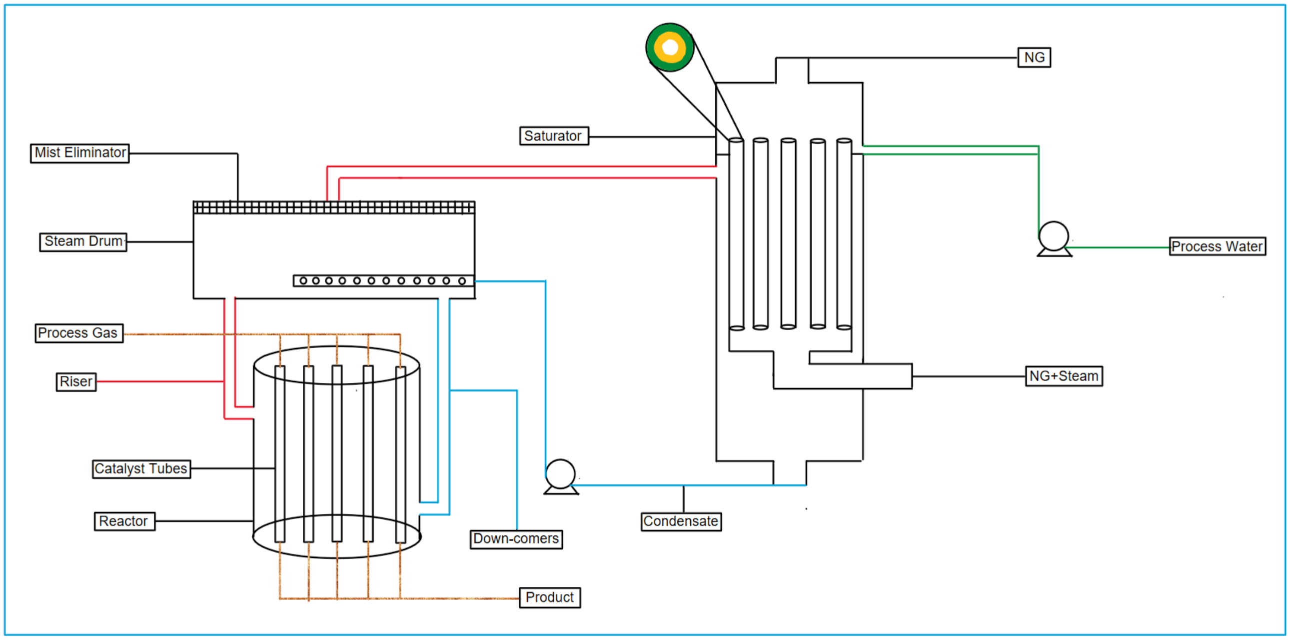
You see how beautifully the Low Selector helped us to tackle the difficulty. To gain deeper understanding, let's have a look at the next page diagrams which represents what has happened.




70%
60%
50%
40%
20%
0%
Washing Water Flowrate
Separator Level
Master FIC MV
FV-1 Opening
FV-2 Opening

Example 3:
You can find steam drums in almost each process plants. Understanding how they work really does not require that much process engineering knowledge since one you understand it you say of course it should happen like this. It is an act of nature.

The process gas passes through the catalyst tubes, the conversion occur, and the product is produced. Throughout the tube, while the reactants are converted to the product, immense amount of heat is produced. To optimize the process and get the best out of the heat produced, water enters the steam drum, comes around the tubes via downcomers, gets heated, via risers as saturated vapor moves up, enters the steam drum, collide with a baffle, and finally passes through mist eliminators and exits the steam drum as pressurized steam free of any water droplets.



When we as process engineer look at other side of the process, we see that we have a saturator which requires approximately the same amount of the pressurised steam. Don't be scared! The saturator is a vertical heat exchanger. Let's see what the purpose of the saturator is and how it functions. Simply, the NG is going to be cracked or reformed in a fired heater. In order to prevent the cocking on the surface of tubes in fired heater, NG is saturated with steam; to saturate NG with steam, NG comes to the saturator and becomes mixed with water with yellow color. Now both NG and process water moves downward alongside the tube. As they move downwardly, the pressurized steam which is produced in the steam drum enters the shell side of the saturator and provides a great deal of heat to the tubes. Now the heat by means of convection passes through wall of the tubes and vaporizes the process water which is moving downward in the tubes alongside NG. At the end, saturated NG with steam exit the saturator. The pressurized steam on the shell side which provided the heat, now gets cooled and becomes condensed. The condensate could be pumped to the steam drum, goes down to the reactor via downcomers, gets heated, and you get the story.

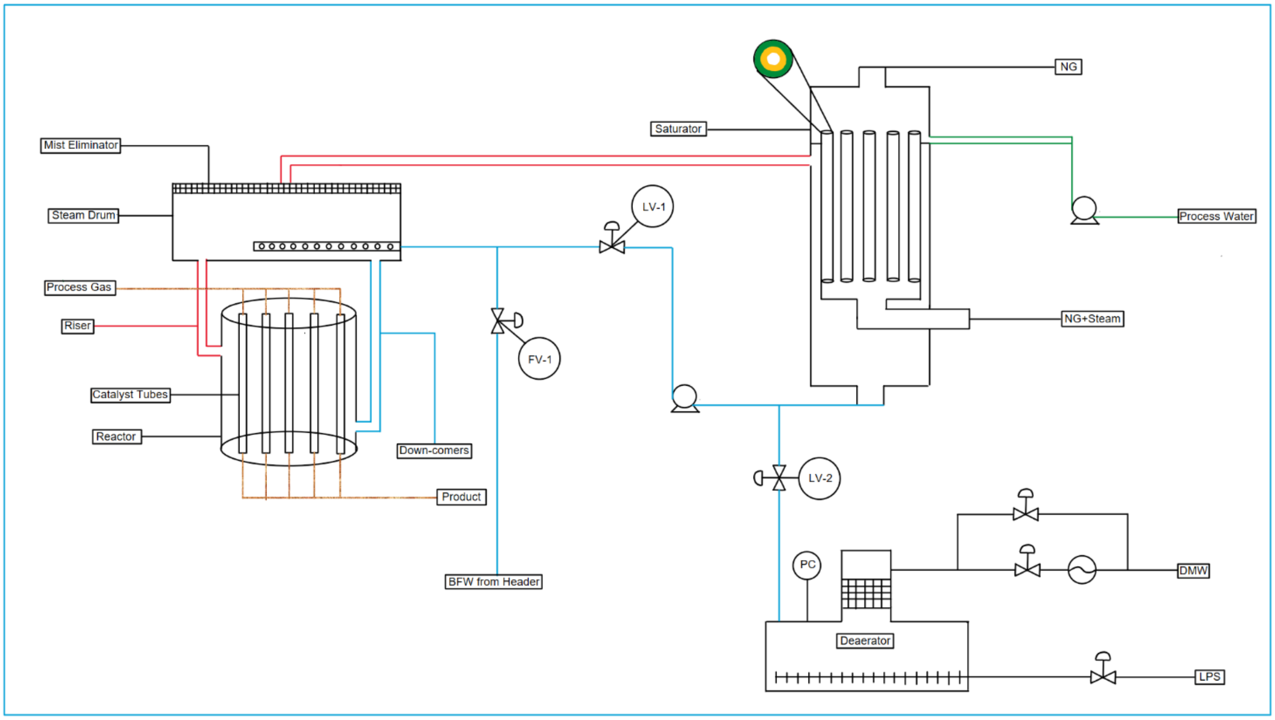
For now let's think like professionals and get out of academic contexts and environment!

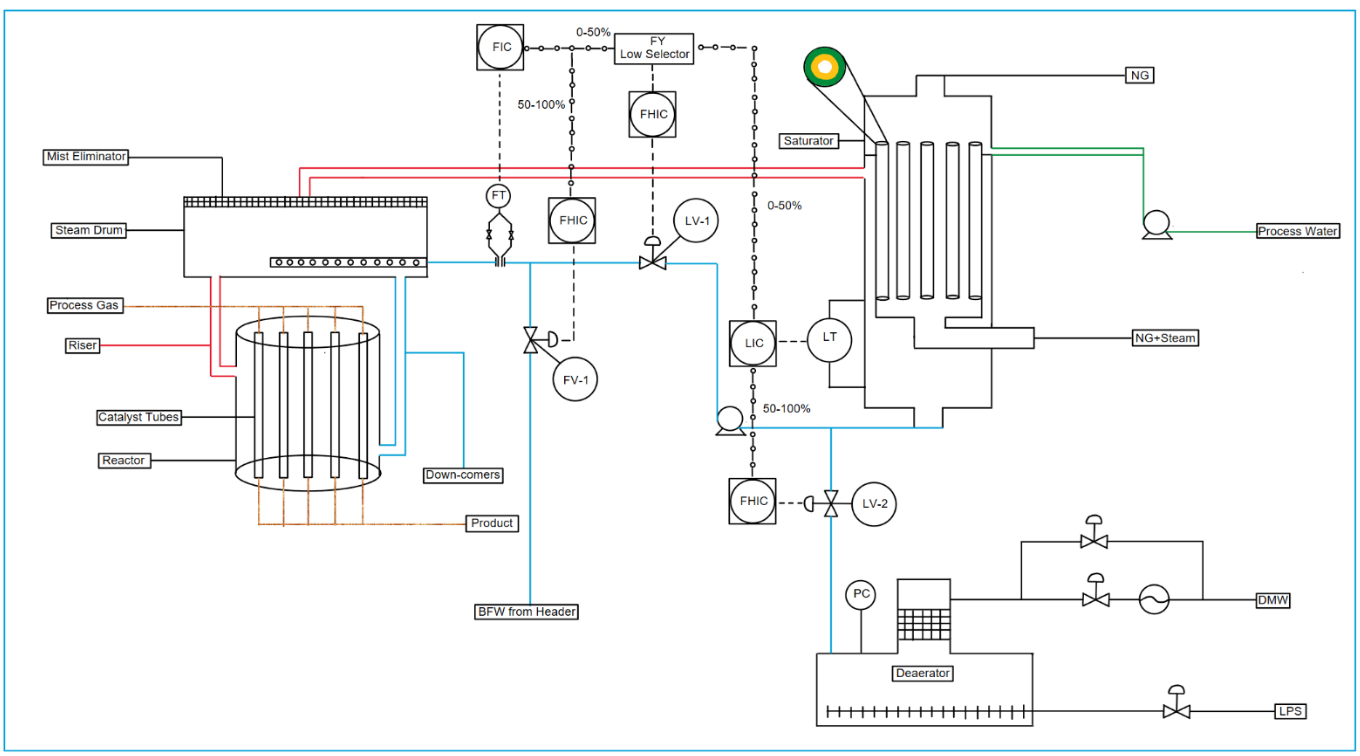
That was the normal operation of the loop and to the extreme point, you might think that even we don't need a control system to control the loop since everything happens mechanically and naturally!

We professional process and advanced control designers also take into account other parameters and conditions. Here are some to mention:

1. Each steam drum has a blow-down flowrate. Simply, the blow-down purpose is to get concentrated chemicals and particles out of the loop so that the quality of the water is kept within the range. From mass balance perspective, there is a loss and thus, make-up water should be added.
2. There are some times that the steam drum and reactor, due to some turbulences, might demand more water to dissipate the heat produced. So additional source of water is a must.
3. During start-ups, at first the saturator is put to the operation, then after one day, the reactor and steam drum assembly is brought to service. It means during start-up we should have another source of pressurised steam. To address the issue, we purchase pressurised steam from a utility plant, add it to the steam header, and finally connect the header to the shell side of the saturator. To be honest, it is not a big deal! The problem is somewhere else. The problem is that when we are at normal operation, we could use the condensate produced in the saturator and send it to the reactor and steam drum assembly. But during start-ups we don't have the steam drum and reactor assembly in operation, and hence, can't send the condensate to the assembly. In order to tackle the problem, we can use the deaerator as the receiver of the condensate during start-ups as the deaerator is the first unit to be put in service in most petrochemical start-ups.
4. If we consider the deaerator route, there is another advantage. Thanks to some turbulences, the reactor and steam drum assembly requires less boiler feed water. In case this happens, the excess water could be sent to the deaerator.

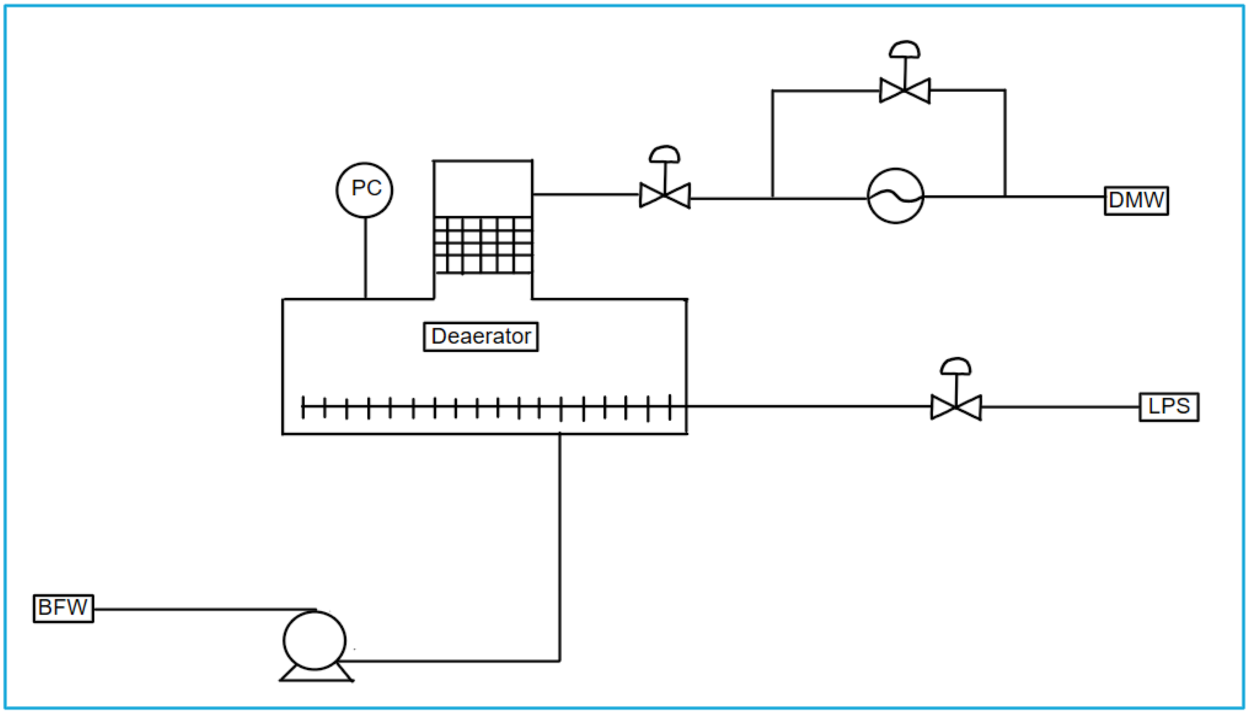
Here is the new sketch and what we should focus on:


NG
Saturator
Mist Eliminator
Steam Drum
LV-1
Process Water
Process Gas
Riser
FV-1
NG+Steam
Catalyst Tubes
Reactor
Down-comers
LV-2
Product
BFW from Header
PC
DMW
Deaerator
LPS


FIC
0-50%
FY
Low Selector
NG
50-100%
FHIC
Saturator
Mist Eliminator
FT
0-50%
Steam Drum
FHIC
LV-1
Process Water
Process Gas
LIC
LT
NG+Steam
Riser
FV-1
50-100%
Catalyst Tubes
Reactor
Down-comers
Product
FHIC
LV-2
BFW from Header
PC
DMW
Deaerator
LPS

Example 4:

Deaerators are essential in almost all plants. Simply we have deaerators to produce boiler feed water or BFW. DMW from polishing unit enters the deaerator via inlet nozzle and is distributed over the packed bed. At the same time the LPS is injected from the bottom and under packed bed. The heat provided by LPS vaporizes a part of water and more importantly help the trapped oxygen to escape; also, to help the process, the deaerator is created spacious so that the oxygen can easily escape.



You see the aim of the deaerator is to eliminate oxygen mechanically. So far, we have talked about packed bed, which increases the mass transfer between exiting steam and DMW; we also talked about LPS injection, which un-trap the trapped oxygen molecules. Here are more initiatives to apply in deaerators to help remove the oxygen.

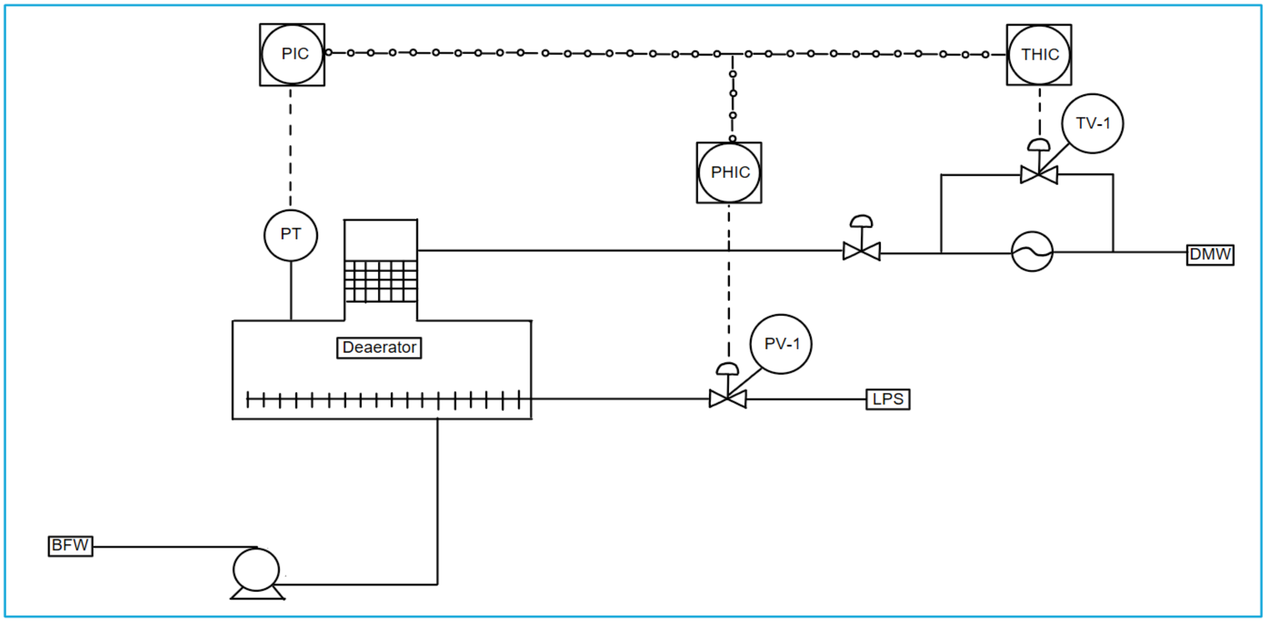
1. Preheating the DMW: As stated providing heat to the DMW vaporizes the oxygen trapped.
2. Keeping the pressure low around 0.5 to 1 barg to help bubbling of the oxygen.

Now let's have a look at it with advanced control viewpoint.

Here the pressure should be kept around 1 barg and it is a function of the heat provided to the deaerator. It is a simple rule, the more the heat, the higher the pressure.

The heat produced inside the deaerator is a function of DMW temperature and LPS pressure. The DMW temperature is determined by the amount of flow passing through the heat exchanger and the amount passing through bypass valve shown above.

Now it is time to reach the conclusion that the pressure inside the deaerator is affected by bypass valve and the valve controlling the LPS pressure. So, the first edition of control system design for this process would be like below:



Don't expect us to explain every step. When we say two control valves impact the process, then you should quickly imagine such configuration in your head.

Here we have not specified the split-range; which one should get 0-50% and which one 50-100%. For previous examples our explanation was that we want to consume less amount of BFW and use process water first to reduce the cost. Based on such explanation, we devoted 0-50% to process water and 50-100% to BFW to delay the use of BFW. In this regard, what is the criteria for the deaerator pressure control split-range?

Since playing with pressure has more quick effects compared to the temperature as you can imagine it, it is preferable to devote 0-50% to PV-1 and 50-100% to TV-2.

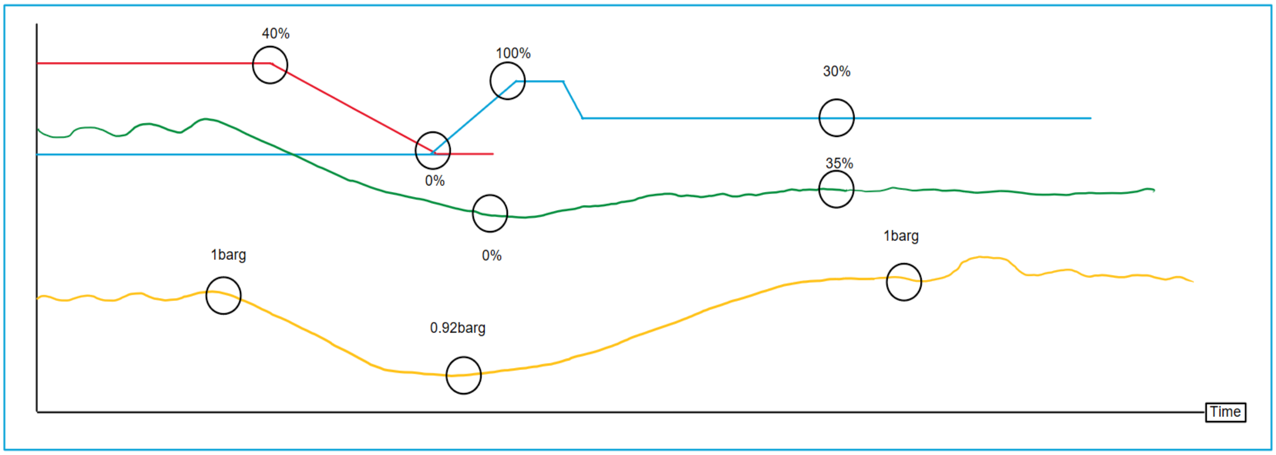
When the pressure in D 7001 is lower than normal, Master PIC would first increase the stripping steam by opening valve PV-1 and if the normal pressure is still not obtained, the DMW temperature is increased by closing bypass valve TV-1. The reverse action takes place when the pressure is higher than normal.

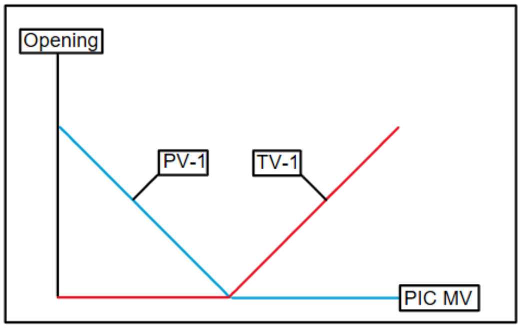
Before going further, let's learn something new and combine the info with the previous and make something!

Direct controller: When the process value increases, the output or MV increases to get back to normalcy.

Reverse controller: When the process value increases, the output or MV decreases to get back to normalcy.

Our assumption is that TIC and Master PIC are direct controllers. Now imagine that the TV-1 is 40% open and PV-1 is closed. Suddenly the pressure decreases and comes around 0.92 barg. Now the Master PIC MV decreases and starts closing the TV-1 and the MV reaches below 50% and thus start opening PV-1. But the pressure is still decreasing so Master P IC lowers the MV to 0. In reality it means the PV-1 should be completely open to increase the pressure. After a while the pressure becomes stable at 1-1.01 barg and still the opening of PV-1 is 100%. After a period of stability, the pressure increases so Master PIC MV increases. The final effect is that the Master PIC behaves in a way that starts closing the PV-1. Let's see all of this in a plot to go deep.



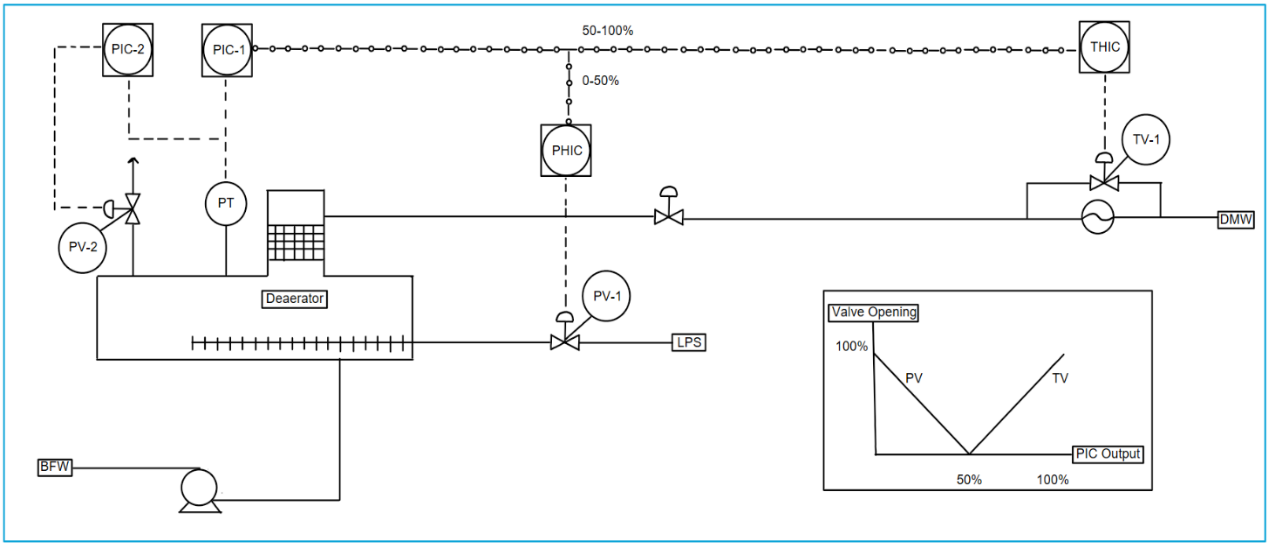


Are we done? Nope! Since deaerators are very important equipment, they should be meticulous care during both design and operation stages. Since the operating pressure is very low, it is almost a normal practice to have Override Control added to the control system we have so far developed.

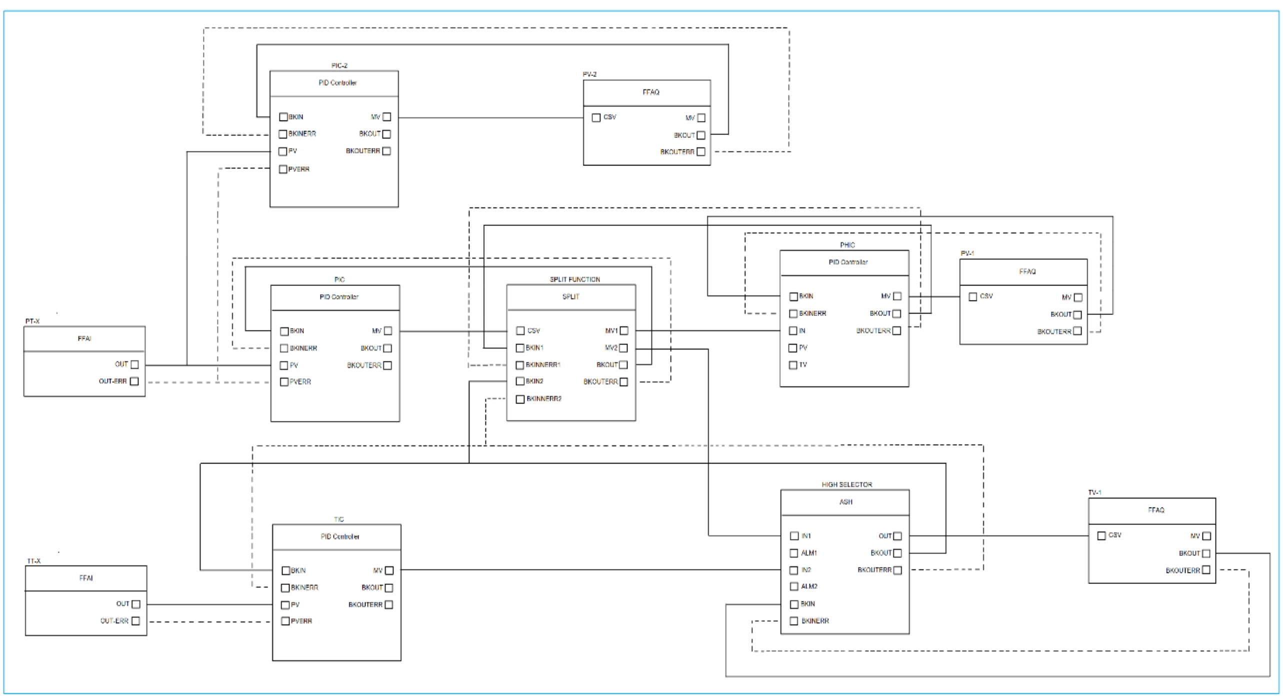
Let's describe the description of the emergency and you will get the meaning of Override Control without extra explanation!

If too much steam condensate is added to the deaerator compared to BFW, Master PIC will not be able to control the pressure, and then Override PIC takes over. The set point of the Override

PIC-7101 is kept slightly higher than the set point of Master PIC. Override PIC will relieve the excess steam to safe location via vent valve PV-2.

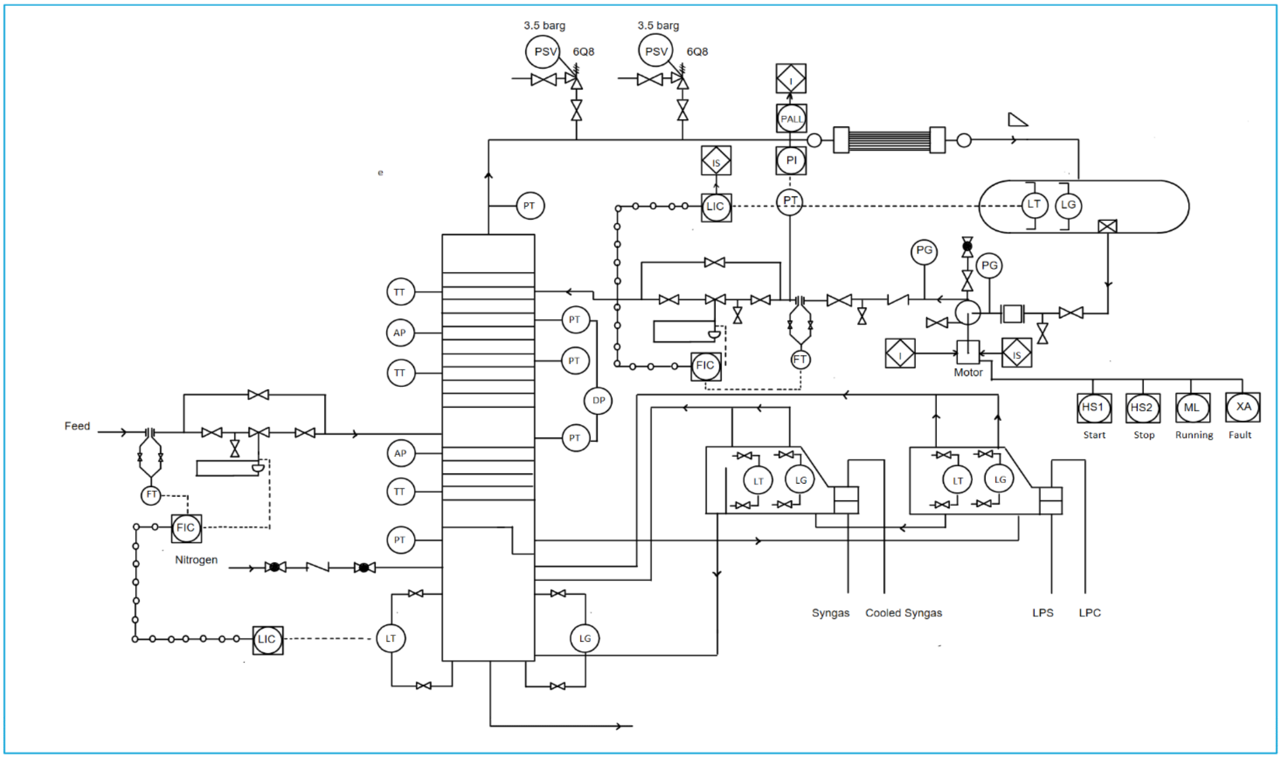


Now we are done! But before going to the next example, we want to show you something wonderful! How is it shown on FCS in the logic form?? Check it in next page.



Example 5:

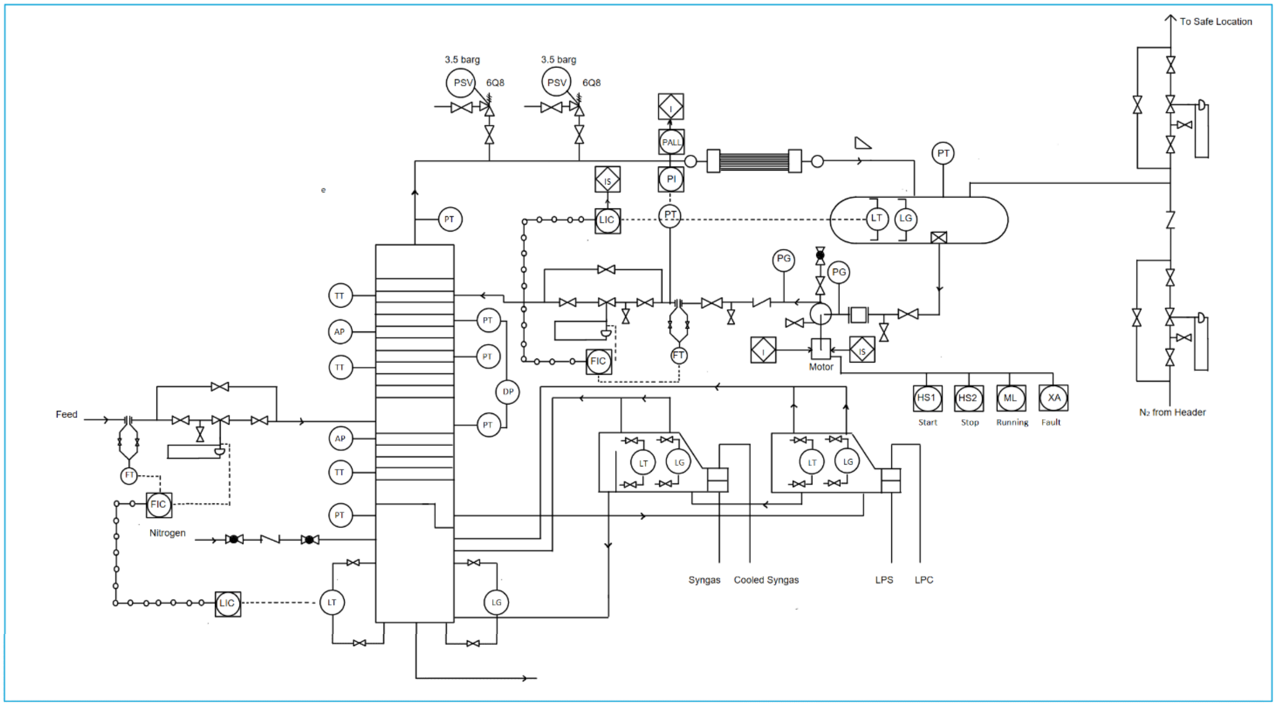
Approximately in all process plants we deal with distillation columns, by which the purity of products is enhanced. Simply a distillation column consists of a tower, an air cooler, a reflux drum, and a reboiler. Maintaining column and reflux drum pressure is a must. Here is the P&ID-like sketch:



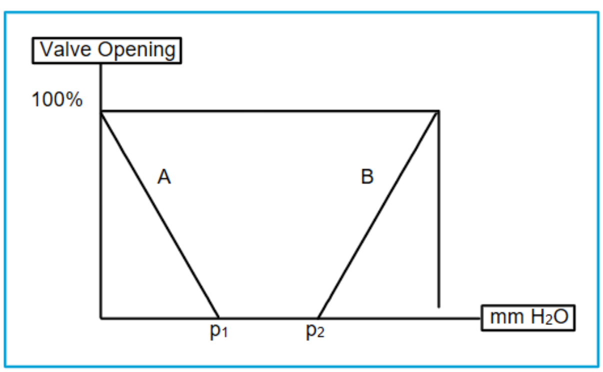
For reflux drum and column pressure control, the pressure control is typically performed by split-range control. Here is the description:

1. At low pressures, nitrogen is added.
2. At high pressure, the vapor is sent to safe location or re-used as the fuel.

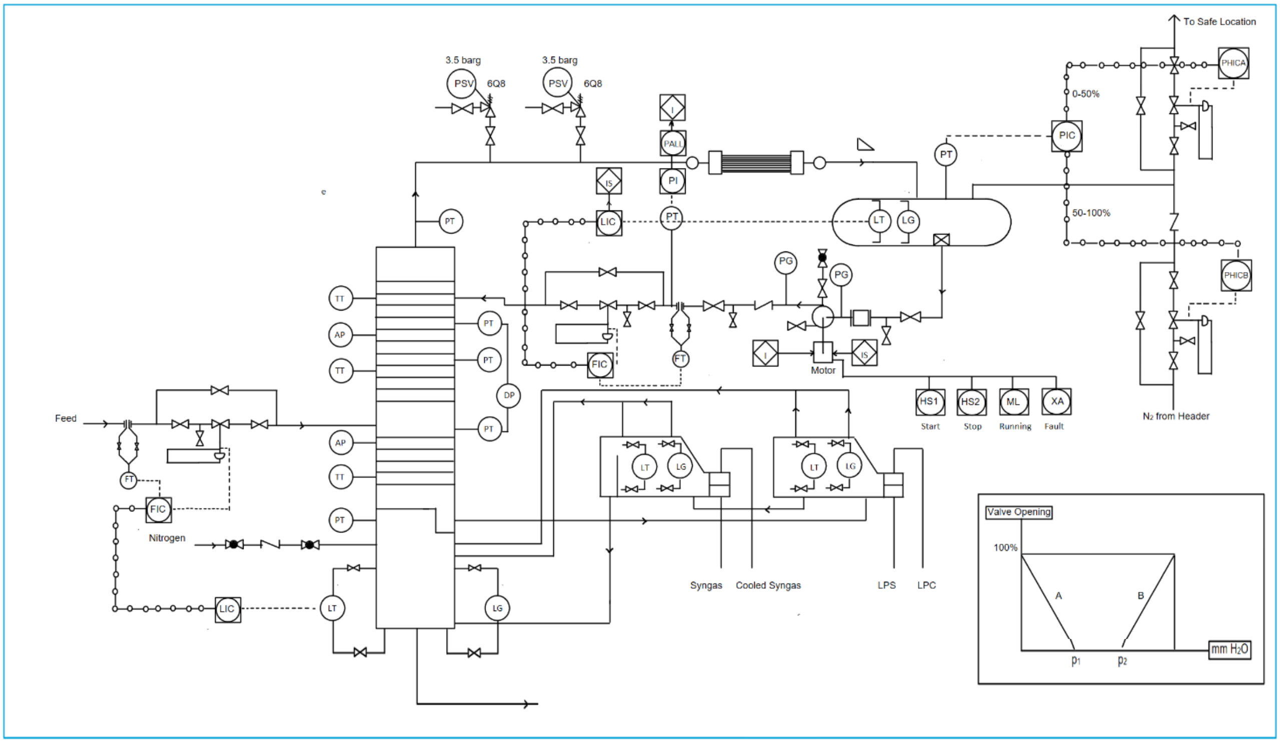
So, the new sketch becomes like below:



The tower should be operated between p_1 and p_2 in say mm H_2O. When the pressure is below p_1 the nitrogen should be added. It is obvious that when we are at the extreme and reflux drum pressure becomes 0 mm H_2O, the nitrogen valve should be fully open to inject nitrogen as much as possible to increase the pressure suddenly and prevent vacuum. In contrast, when the pressure is more than p_2 the PV-2 which vents the excess vapor to the atmosphere starts opening. It is apparent that when we are at the extreme and reflux drum is going to experience overpressure, the PV-2 should open completely to discharge as much as possible.

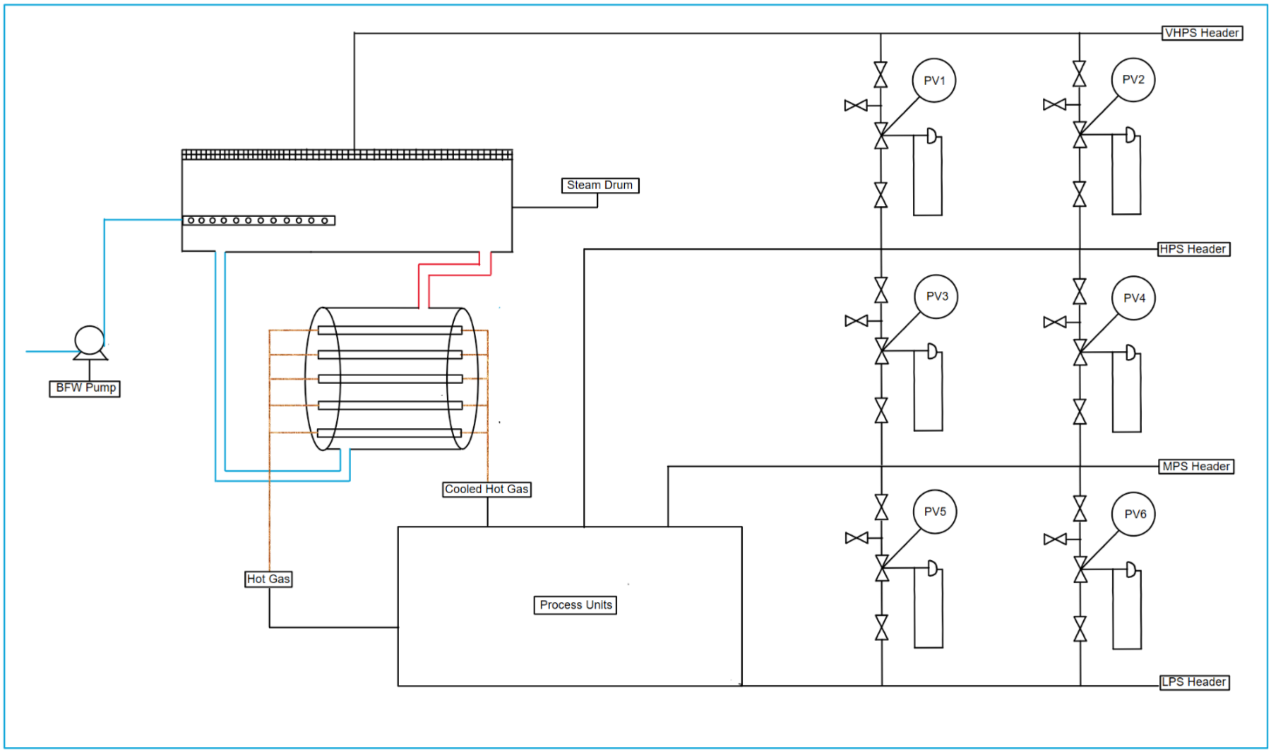


Now it is time to draw the controllers and split-range control on P&ID.


To Safe Location
3.5 barg
PSV
6Q8
3.5 barg
PSV
6Q8
PALL
PI
PT
LIC
IS
LT
LG
PT
PIC
0-50%
50-100%
PHICA
PHICB
PG
PG
FIC
FT
Motor
IS
HS1
HS2
ML
XA
Start
Stop
Running
Fault
N2 from Header
TT
AP
TT
PT
PT
DP
PT
AP
TT
PT
Feed
FT
FIC
Nitrogen
LIC
LT
LG
LT
LG
LT
LG
Syngas
Cooled Syngas
LPS
LPC
Valve Opening
100%
A
B
p1
p2
mm H2O

Example 6:

Do you remember the steam headers we talked about in example 3 of temperature controllers. In that example we talked about temperature control using quench water but we did not talk about the pressure control of each header. Here is one of the common designs used in control of header pressure.

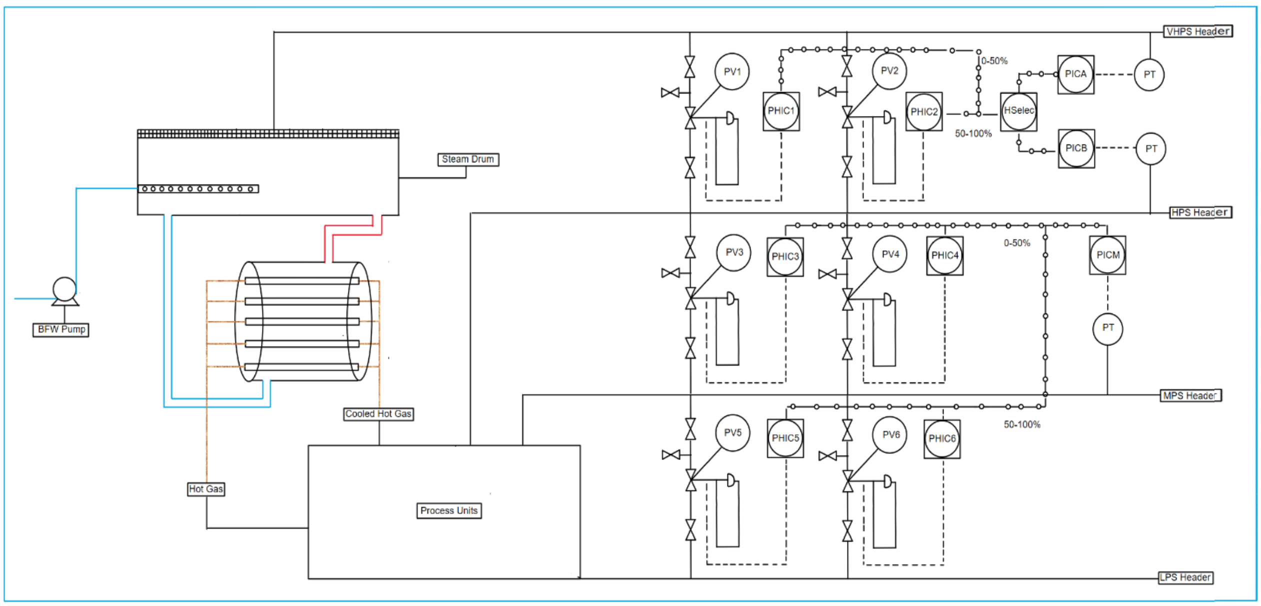


Before going further, let's at first understand the whole process of steam generation and steam headers.

The hot gas from Process Unit 1 passes through the heat exchanger; at the same time the BFW pump sends boiler feed water to the steam drum and via down-comers enter the heat exchanger. The BFW surrounds the tubes in which hot gas passes and as a result, exchange heat with the hot gas, gets vaporized, moves up to the steam drum through risers and finally enters the very high-pressure steam or VHPS. Since Process Units U4, U3, U2 need high pressure, medium pressure and low pressure respectively, we have to produce different types of steam with different operating pressures. Keeping this in mind, we have to use pressure valves to be able to reduce pressure from a high pressure to a lower pressure.

Just check the following algorithm to get familiarized with different approach towards each header.

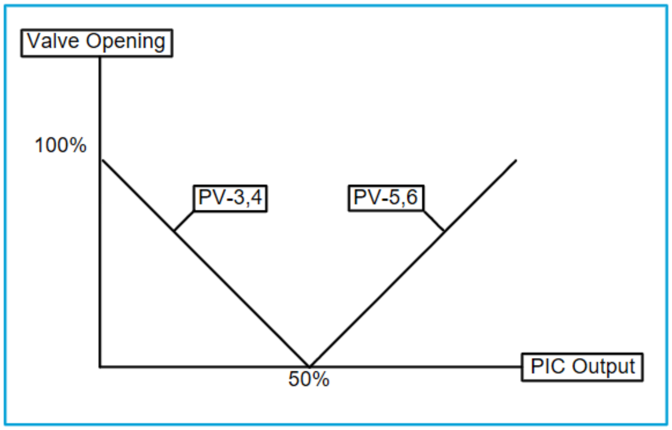
Now let's analyze the applied advanced control used for control of header pressures. The PIC- gets the PV from VHPS, calculates the MV and sends it to the high selector. Simultaneously, the PIC- gets the PV from HPS, calculates the MV, and sends it to the high selector. Now the high selector selects the higher MV. If it is in the range of 0-50% then it is sent to PV-1 but if it is in the range of 50-100% then it is sent to PV-2. For the process control specialist both HPS header and VHPS are important since VHPS header supports large turbines while HPS header supports small turbines. Thus, the process control specialist should design the control system in a way that both headers are checked regularly. Also the control applied is split-range since here we have two control valves. If the PV-1 is not able to handle all flow, then PV-2 comes to service to prevent any disturbance in both flow and pressure.



Now look at the MPS header. The process control specialist this time just focuses on MPS header pressure and uses only one PIC to manipulate 4 control valves namely PV-1, PV-2, PV-3, PV-4. The PIC checks the PT data or PV against set point and sends a MV. Now the MV is split. For MVs between 0-50%, the set of PV-3 and PV-4 take control of the header whereas for MVs between 50-100%, the set of PV-5 and PV-6 take control of the header. It is new to you that a PHIC like send MV to two control valves. What does it mean? How in reality is it used.

Simply for steam let-down stations it is beneficial to have a “stand-by” control valve; one problem is that the control valves experience high differential pressure and temperature at the same time; hence the failure rate from process and maintenance perspectives is high. So, the designer has foreseen that. The control room operator can have one of these PVs in cascade with Master PIC and put another one in manual status; or he or she can put both of them in cascade with Master PIC. The result is that the opening for both of them reduces when both are in service, which is obvious.

Now image that the PIC is direct; let’s see the impact. If the MPS header pressure goes up, it means the PIC starts increasing the MV. Let’s assume it goes to the extreme and sends the MV of 100%. From process viewpoint, the PV and PV should open completely to release the header pressure; In fact, their function is to preclude the overpressure of the line. Now, if the header pressure decreases then the PIC sends a lower MV. On the extreme point, let's assume that the PIC sends a MV of 0%; from process point of view, the PV- and PV- should completely open to increase the header pressure. It is clear that when set of overpressure valves are open then the set of under-pressure valve should be closed and vise versa. Finally, the plot would be like this:



What if we want the controller to be reverse?

If the MPS header pressure goes up, it means the PIC starts decreasing the MV. Let's assume it goes to the extreme and sends the MV of 0%. From process viewpoint, the PV-5 and PV-6 should close completely to back-up the header pressure; In fact, their function is to preclude the under-pressure of the header. Now, if the header pressure decreases then the PIC sends a higher MV. On the extreme point, let's assume that the PIC sends a MV of 100%; from process point of view, the PV-3 and PV-4 should completely open to increase the header pressure. It is clear that when set of overpressure valves are open then the set of under-pressure valve should be closed and vice versa. Finally, the plot would be like this: