Plantwide Control of Chemical Processes
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Lecture - 5
Advanced loops (contd) and multivariable systems

Good morning all of you welcome back, I think this is the fifth lecture in this is the fifth lecture of this course.

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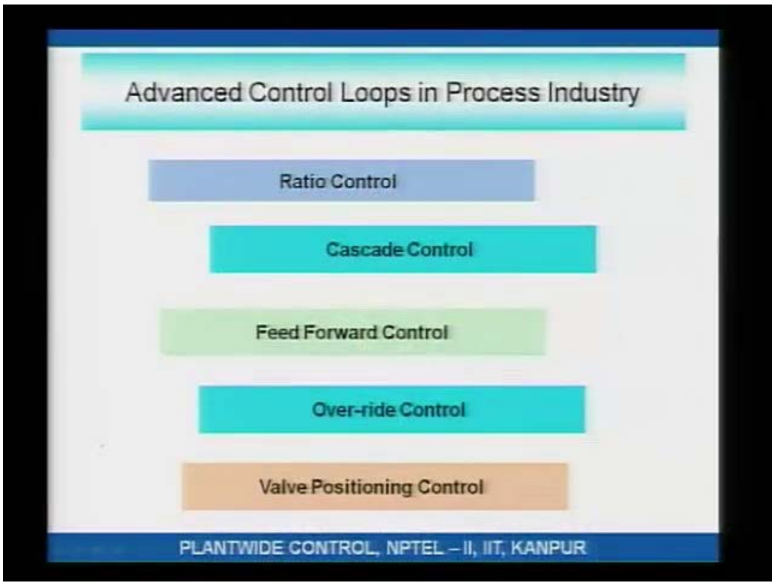

Last time we were looking at advanced control loops that are very commonly used in the process industry namely ratio controllers, cascade controllers, feed forward controllers, over ride controllers, continue and discuss over ride control and valve positioning control, over ride control. Well over ride control like the word indicates an overriding circumstance occurs during process operation which can potentially result in a safety hazard.

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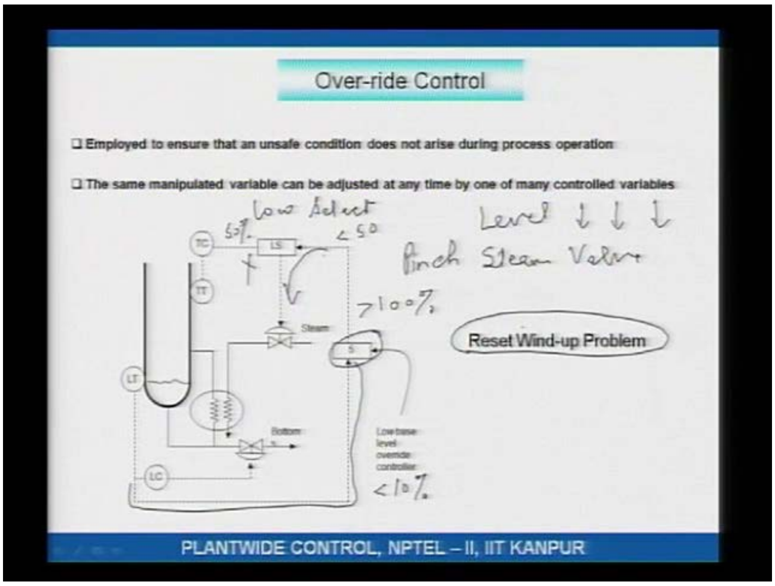

So, then you have over ride control to ensure that the unsafe condition does not arise during process operation, and what override essentially means is the same manipulated variable is adjusted by different controllers. For a set of conditions for example, the steam value is moved by the level controller, if an unsafe condition develops or the steam valve is controlled by the temperature controller, if the, if an unsafe condition develops then the steam valve is moved by a level controller and so on so forth. So, this is best explained instead of me blabbing on and on, I think the best thing to do would be to explain it using an example. So, here is a very simple example, this is the bottom of the stripping section of a distillation column, you got the re boiler which is taking in steam, this steam is is causing vapor to boil up.

Now, ordinarily what happens is the steam valve is moved by the temperature controller this LS is actually low select, LS is actually low select that means it takes in the signal the output of the temperature controller as well as this guide which I will explain a little later, whichever is the lower of the two that is the signal that gets passed through the steam valve. Now, what we are doing on the other side is the level in the bottom sump of the column is controlled using the bottom's flow rate. Alright, it may so happen that the level is reducing and this valve is fully closed and yet the level still goes on reducing.

Now, you would not like the level to go down below say 10 percent because then the tubes will get exposed, the tubes in the re-boiler must always be dipped in liquid and no liquid in inside the re-boiler is an unacceptable condition, because then the re-boiler or the the tubes in the re-boiler may get burnt.

So, to prevent that what you would like is if the level is going down and is continually going down even as this valve has fully closed, you would like that the steam be reduced, you would like to pinch the steam valve.

So, if level is decreasing and it continues to decrease steam valve must be pinched, steam valve should be pinched the steam valve. So, ordinarily the steam valve is being moved to hold a tray temperature constant, but should the level go below and continue to go down you would like that the steam come under level control. So, what then that will what then you would like is that the steam valve should be pinched so that less steam is given and as less steam is given there will be less boil up and so the level will come back up. So, this is implemented here in this way. Here is the level signal, this is the level signal, you multiply this level let us say level is 50 percent, you multiply it by 5 you know if the level is not too low this signal will be usually greater than 100 percent.

Now, let us say the level is going down, level goes down to let us say 20 percent. 20 percent times 5 is 100 percent exactly equal to 100 percent. Now, the level is further going down what will happen is if level goes below 20 percent this signal will go below 100 percent. If level continues to go down then this signal ultimately will become less than this signal and the low select will now start sending this signal to the to the steam valve.

So for example, let us say temperature controller output is 50 percent, if level goes if the level goes below 10 percent then this signal goes below 50 percent and then the low select will pass this signal and this signal will not be passed. So, this would if the level continues to go down below 50 percent below 10 percent then this signal will go below 50 percent and this valve will get pinched. So, this is an example of an override controller where the overriding circumstances are reducing level in the bottom sump of the column. If the level continues to go down you would like that the steam valve will be pinched. So, this is an example of an override controller, this need not necessarily be a proportional, a multiplier only it could be a PI controller.

In case it is a PI controller note that ordinarily this would be going through the PI controller will keep integrating whatever is coming from here and that can cause this output to saturate beyond 100 percent, way beyond 100 percent and this is known as the reset wind up problem, those of you if you do not know about it, I mean its covered in reasonable detail in any of basic control text books. So, one has to be aware that these override controllers by the very nature that the overriding circumstances is an exceptional circumstance which does not normally occur. Therefore, the controller if it is a PI controller would actually be saturated because of reset wind up and things have to be done to circumvent that problem which we will not cover here.

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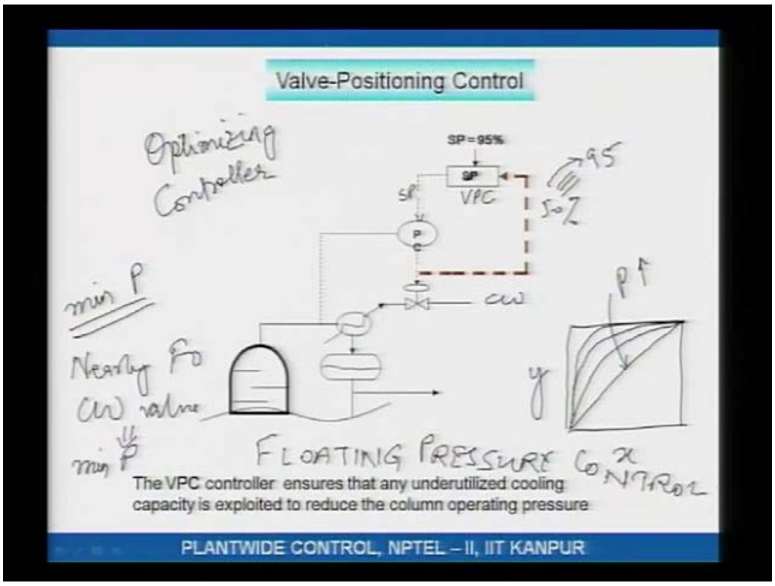

Another very useful control structure or control controller is called the valve positioning controller, sometimes also referred to as an optimizing controller or optimizing control. What we are doing here is that this is again best explained using an example. Ordinarily in distillation columns what you have is the hot vapor is condensed in the condenser using cooling water. So, if the pressure of the column is increasing that means more vapor needs to be condensed, what you would do is you would increase the cooling water flow, and therefore condensation rate would go up and the pressure will get back down. So, this is how ordinarily pressure is controlled in most industrial columns.

You typically do not have a valve here because for industrial scale systems the vapor flow rate is very large and to accommodate that vapor flow rate the pipe would be very thick or a large diameter pipe and to install a valve in that I mean that would be an expensive valve. So, this is usually not the case in industrial columns. By design you would like to operate the distillation column at as low a pressure as possible. Why is that? That is because if you look at the vapor equilibrium for example, for a binary systems if you look at the x y curve x is the liquid phase compassion and y is the vapor phase composition in equilibrium with the liquid phase composition, you would have seen this in your text books so many times.

This vapor liquid phase envelop let us say looks like this at a certain pressure, if you keep in decreasing the pressure what you would see is this phase envelop moves away from the 45 degree line. So, in other words if the pressure is increased the x y envelop moves towards the 45 degree line. What that essentially means is as the pressure, operating pressure of the column is increased the separation gets more and more difficult. What is that suppose to mean, what is that suppose to imply? That means to get the same separation you would require more and more reflux. More and more reflux implies you would be consuming more and more steam. Therefore, per kg product your steam consumption would go up.

So, what is desirable then is that your column be operated at as low a pressure as possible. So, I would like to operate the column at minimum possible pressure. Now, there is a set point this should be VPC valve positioning controller. Now, to understand what the valve positioning controller is doing consider the following, let us say my valve is my cooling valve is 50 percent open. What that essentially means is if I start putting in more cooling water condensation of vapor will go up because I have got colder tubes in the condenser. Now, because condensation rate will go up for that means is the operating pressure of the column would go down.

So, I am initially at steady state, my valve, cooling water valve is say 50 percent open, to reduce the operating pressure of the column in order to minimize steam consumption what I would like is that the cooling water valve be opened. In other words what I would like is that my column be operated all the time at nearly fully open cooling water valve because a nearly open cooling water valve implies the column is operating at as low a pressure as possible. I hope this is clear, what I am saying is I would like to operate the column at nearly fully opened cooling water valve because this is what implies that I am operating the column at as low a pressure as possible.

How is it then done then done? You measure the valve the output of the pressure controller which is the valve position. You measure you have this valve position, you compare it with the set point since you wanted to want the valve position to be nearly fully open. Let us say this set point is 95 percent. Now, what happens is this valve position controller decreases the set point of the pressure controller. So, this was initially 50 percent open since it is not at 95 percent and I need to open this valve further the valve position controller decreases this set point. So, what that essentially means is compared to the set point now my column is at a higher pressure, in order to bring the column at the set point pressure as at the desired pressure this pressure controller would increase the cooling water flow because I want to increase condensation to reduce the pressure.

So, as the set point of this pressure controller is decreased pressure controller will open this valve and slowly, but surely what was 50 percent open would slowly, but slowly approach the set point which is so this will go to 95 percent through the action of the valve positioning controller. What the valve positioning controller is essentially doing is it is saying that my valve is cooling water valve is not fully open that means I can reduce the pressure of the column so when I reduce the pressure of the column the pressure controller opens the cooling water valve and so slowly, but surely my cooling water valve approaches nearly fully open condition and once it approaches that condition what I have is my column is operating at as low a pressure as possible which is what I desire. So, this is an example of a valve positioning controller this is also sometimes referred to as floating pressure control, floating pressure control. Maybe I should give you another example of valve positioning controller.

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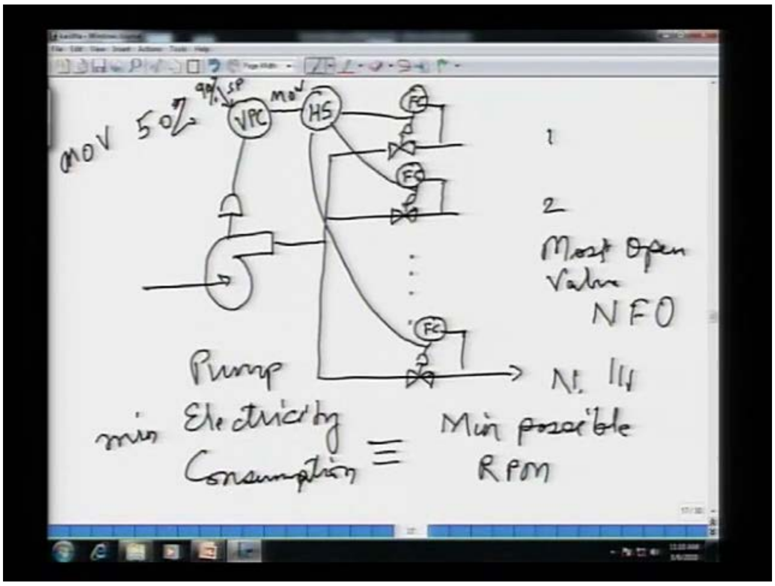

For example, consider let us say I have got a big pump and let us say it is a variable speed pump. That means its rotational speed is adjustable this is indicated by this valve and this pump is actually feeding n number of downstream units in parallel. So, you are feeding whatever you wish to feed to process number 1, process number 2, process number n. Every process requires a certain amount of feed and that is ensured by having a flow controller and each of these flow controllers has a set point which is the desired feed rate to the process. Note that I want to operate my, you know whatever is the demand for process 1 that is a set point for this flow controller, whatever is the demand for process 2 that is the set point for this flow controller, whatever is the demand for process n that is the set point for this flow controller.

Now, whatever is desired by each of those processes that must be given. This pump since it is a big pump consumes a lot of electricity and electricity is expensive. So, what I would like to do is while meeting the demand of all the processes I would like to minimize the RPM at which this pump is rotating while meeting the demand, while meeting the process demand. So, I want to minimize electricity consumption minimize electricity consumption, pump I want to minimize pump electricity consumption and the way to do it is you would like this is equivalent to operating the pump at the minimum possible RPM rotations per minute. Now, how do I decide whether the RPM is minimum or not? Well to decide that let us say the most open valve right now, pump is operating at a certain RPM there are certain flow set points which are for process 1, process 2, process n and the most open valve see each of these valves will have a certain opening.

Let us say the most open valve is 50 percent open most open valve is 50 percent open MOV most open valve is 50 percent open, the other valves are less than 50 percent open, let us say 20 percent, 30 percent. Now, what that means is I am unnecessarily pinching this most open valve, unnecessary pressure drop is being taken across the valve and what that implies is that I am generating too much pressure by rotating the pump at a high RPM. So, if the most open valve is only 50 percent open what that means is I can reduce this RPM. If I reduce this RPM pressure here would decrease, flow across the valve would decrease and in order to maintain the flow that is demanded by the process the flow controller would open the valve.

So, till when can I continue to decrease this valve well to reduce the RPM till the most open valve becomes nearly fully opened. So, this minimum electricity consumption which is realized by minimizing the RPM of the pump is equivalent to saying that I would like the most opened valve to be nearly fully open. How do we realize that? Well I have got my valve positions here, if I send it to a high select, which will select the output of this high select is the most open valve. I send this to a valve positioning controller, the set point of this valve positioning controller is let us say 90 percent or 80 percent, this is the set point.

If this most open valve is only 50 percent open valve positioning controller will reduce the RPM, as the RPM is reduced in order to maintain the flow in order to maintain the flow the flow controller will open the valve and this opening will continue till the most open valve MOV, till the most open valve is almost 90 percent opened. So, this is you know another example of application of valve positioning controller and it is for this reason that valve positioning control is also sometimes referred to as optimizing control.

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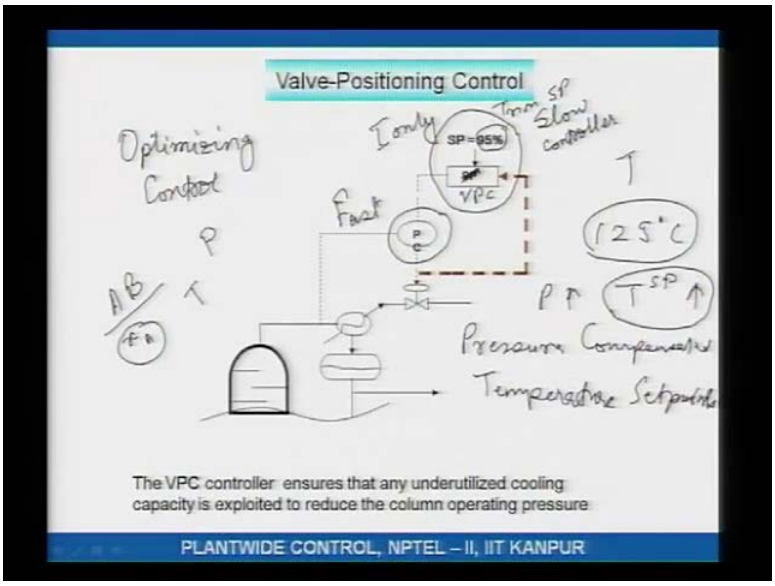

Optimizing control, that is by implementing valve positioning controllers what you are trying to do is either minimize steam consumption, minimize electricity consumption. Another place that I know it is used is to maximize production or you know maximized throughput optimizing controllers are also used in that application we will talk about that through the course, but the point is valve positioning control is routinely employed in order to make your operation as economical as possible.

By the way getting back to since since this is there I should highlight this, you see the pressure when you have this kind of a system in place the pressure of the column will float. So, days are hotter so since the days are hotter therefore, the the minimum achievable operating pressure would be actually higher, nights are colder, energy is anyway getting you are losing more heat, the column is losing more heat probably at night since the nights are cooler, the operating pressure of the column would be slightly lower.

So, if you look at the diurnal cycle you will see that the set point of this pressure follows the diurnal cycle, in the days pressure increases at nights pressure decreases. Now, since the pressure is floating note that if you take a binary mixture and A B binary mixture let us say for a given P for a given pressure if you specify composition of one of the components the other mole fraction would be 1 minus that. So, if you if you specify let us say x A and if you do a bubble point calculation the temperature at which the mixture boils let us say a 30 percent a mixture boils at a pressure of 1 atmosphere is uniquely determined, it is a unique number.

So, what is done because temperature measurements are much more robust than composition measurements, what you essentially do is in order to hold the separation instead of directly controlling compositions, what is typically done is you hold the tray temperature of a certain tray inside the column constant by manipulating either it is a re-boiler duty or manipulating the reflux or both and these situations will, but the point is if the pressure itself is changing the temperature at which the, if the pressure changes the temperature at which you will get x A composition will also change.

So, in floating pressure control if you are implementing temperature controllers then you will have to have pressure compensated temperature set points, I am just to just to make the point, just to clarify it further what I am essentially saying is if the column is operating at 1 atmosphere or slightly above atmospheric pressure, let us say the temperature set point that gives you the right kind of separation is 125 degree Celsius. Now, if the operating pressure of the column goes up because of the action of the valve positioning controller then for the same separation at the higher pressure, same composition liquid will boil at a higher temperature, therefore the temperature should be higher.

So, if pressure goes up temperature set point should also go up, by how much well that depends on what kind of a mixture you are separating and we will cover this later, but please be aware in order to realize energy savings if you are implementing temperature control on the column while the temperature set point of the temperature controller will have to be adjusted depending on what the current pressure of the column is. Another thing that I would like to highlight is that this pressure controller is fast. Now, it is tuned to be for a fast and snappy response, this optimizing controller, this valve positioning controller would be a very slow, this would be a, this would be tuned for a slow response.

What that essentially means is you do not want to change the pressure set point too quickly. You you change the pressure set point slowly, but surely and the action of the pressure controller will cause the cooling water valve to open. Since, it suppose to be a slow controller many a times these valve positioning controllers are I only integral action only, just a slow integrator. Another thing why is this not 100 percent I could have given a set point of 100 percent. Well, if I give a set point of 100 percent then because of local disturbances should the pressure of the column increase? This valve is already 100 percent open I lose pressure control, because I cannot increase the cooling duty anymore because the valve is already 100 percent open.

So, to reject pressure to to to reject disturbances that cause pressure surges, small pressure surges I still need the set point cannot be 100 percent, I will still need some slag so that should the pressure increase I am able to, I am able to do what? I am able to this pressure controller can still increase the cooling water duty to take care of local disturbances. So, there is back off or this trim in the set point will always be there, this will never be 100 percent, it will be less than 100 percent. How less that depends on the system, that depends on how big the pressure surges for example, over here.

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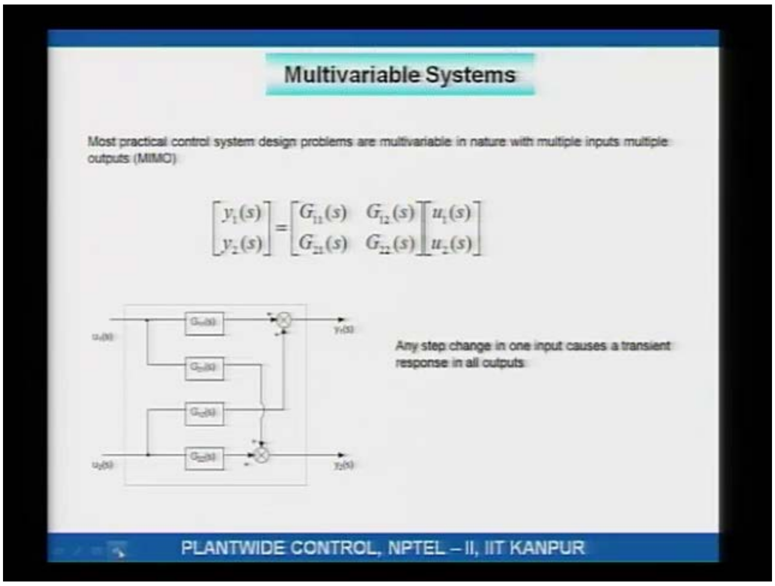

I think that takes care of all the advanced control systems that we have last, but not least well this is not this is not the end we are going to take a look at multivariable systems. Well if you look at any reasonable simple chemical processing, if you look at a displacement column, if you look at a reactor, just to just to motivate the problem let me give you a few examples.

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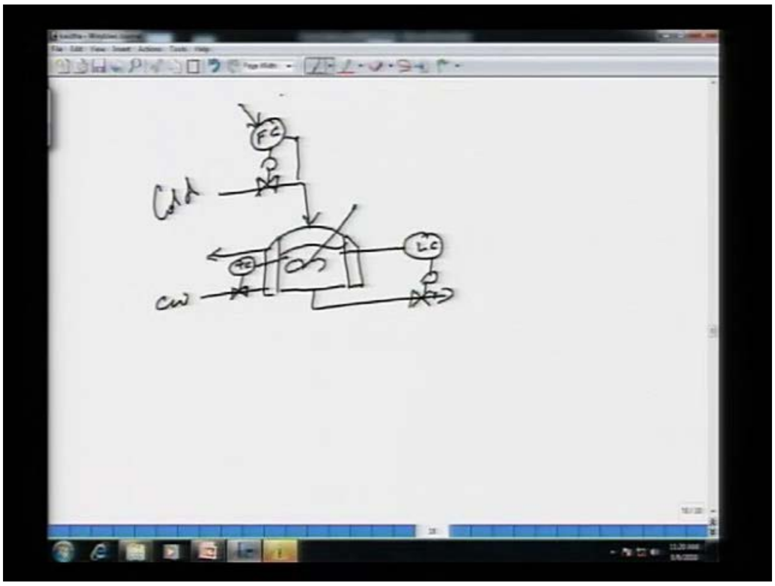

Let say I have got a CSTR, the reactants are flowing in and just because just to show that it is a CSTR products and reactant mixture is flowing out, a reaction is exothermic so I have got some cooling circuit there and which is indicated, let us say it is a jacketed CSTR and the heat is removed by circulating some cooling water and let us say I am controlling the temperature by adjusting the cooling water flow rate and level let us say is being controlled by adjusting the flow out and let us say this is under flow control. If the set point of this flow is increased or decreased that means if the flow rate of this changes do you think the temperature of the reactor will remain where it remains or do you think it will get disturbed?

The temperature will deviate obviously let us say the feed is cold, you are putting in more cold feed, this cold feed when it mixes with the reactor reaction mixture in the reactor it will cause the temperature to go down. As the temperature goes down this temperature controller will adjust the cooling water flow rate to bring it wherever it needs to be brought. The point is whatever you do in this loop affects this loop, this is what we mean by a multi variable you know what I do here affects not only this, but that, that and that also. This is what is referred to as a multi variable control system and just to explain this further a single input single output control how does a single input single output control system look?

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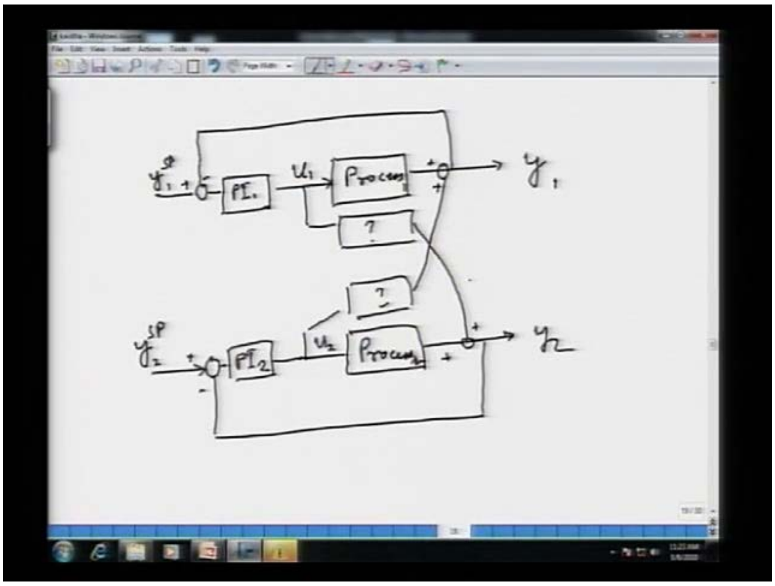

Here is my process, this is the output from the process, I take it back, this is the set point for y let me call it y 1, this is y 1 set point plus minus this goes to a controller let us say it is a PI controller process 1 which adjusts an input. Well, this is a single input single output system. What would be a multi variable system? I also have a process 2, I have an output 2 which is being controlled by adjusting input 2 and I have a PI controller let us say that does that. So, this is shown here. So, I have got y 2 set point, I have got PI controller number 2 which is adjusting u 2.

Now, even if the controller is not there if I move input 1, y 1 will get affected cause and effect relationship. However, y 2 also gets affected. How do your account for that affect? Well essentially what we are saying is and I will put something in there. When I move input 1 not only is y 1 affected y 2 is also affected. Similarly, when I move, if I do not look at the controllers, I have just look at u 2. If I move u 2 not only does y 2 get affected y 1 also gets affected and whatever I put in these blocks these blocks marked question mark, well that should, that represents the interaction, these question mark blocks actually represent interaction between the two loops.

So, this is actually a multi variable system where I do something here, it affects this as well as that. I do something there it affects that as well as this. So, this is in short a multi variable system and there is interaction between the inputs and outputs. Everything is not diagonal so to speak. Here is without the controllers what we have is u 1 affects y 1 through this transfer function G 1 1 and the way to interpret the subscripts is the first subscript is if I say G i j.

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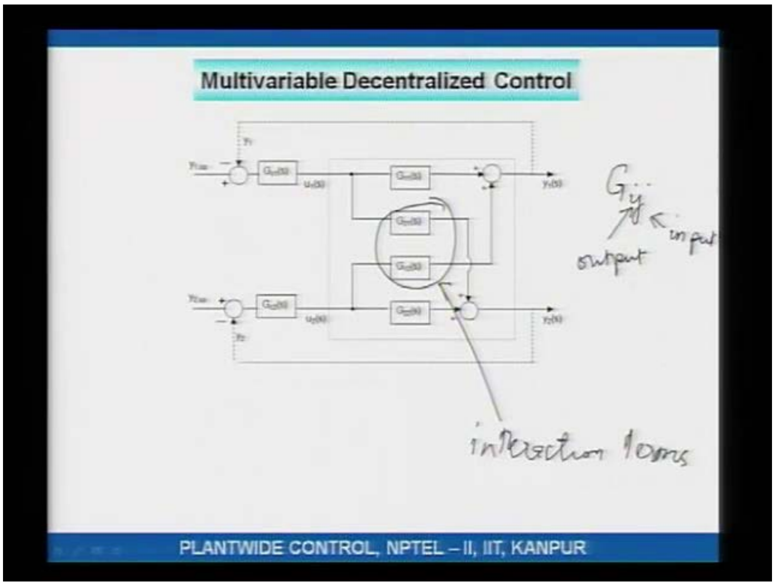

If I say G i j, i refers to the output, y refers to the input, this is the nomenclature or this is how matrix algebra is defined as. So, when I say G 1 1 this G 1 1 is to be interpreted as effect on output 1 of input 1. If I look at G 2 1 what is this? This is effect on output 2 of input 1 you can see this, effect on y 2 of u 1. So, that is refer to as G 2 1. Similarly, G 1 2 is effect on output 1 of input 2 that is effect on y 1 of u 2. You can see that these these two G 2 1 and G 1 2 these are the interaction terms.

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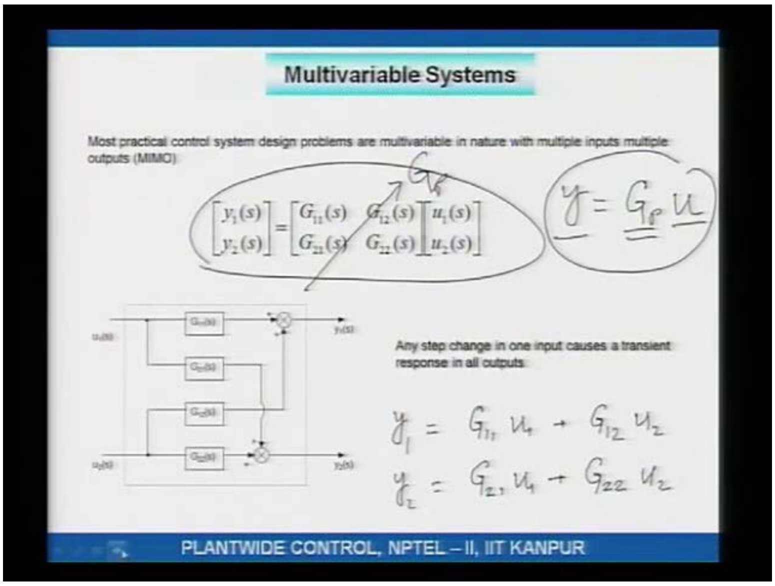

I mean looking at it slightly mathematically what we are essentially saying is what we are essentially saying is y 1 is equal to G 1 1 u 1 plus G 1 2 u 2, y 2 is G on 2 of 1 of u 1 plus G on 2 of 2 u 2. When these two, this is this is the input output relationship. You can see that y 1 is affected not only by u 1, but also by u 2. Similarly, y 2 is affected not only by u 1, y 2 is affected not only by u 2, but also by u 1. So, when we write these two equations in matrix form this is what we get in matrix form, these are the same two equations written as in matrix form.

So, what we are essentially saying is y vector is equal to let us call this G p matrix, G p times u and even though we have shown only a 2 by 2 system here we can have a more complex system. It could be 3 by 3, 4 by 3 it need not necessarily be square, it could be non-square and so on so forth. The most general representation would be in this matrix form. So, we have just looked at the matrix description of a multi variable process, simplest of them being a 2 by 2 2 by 2 system, 2 inputs 2 outputs.

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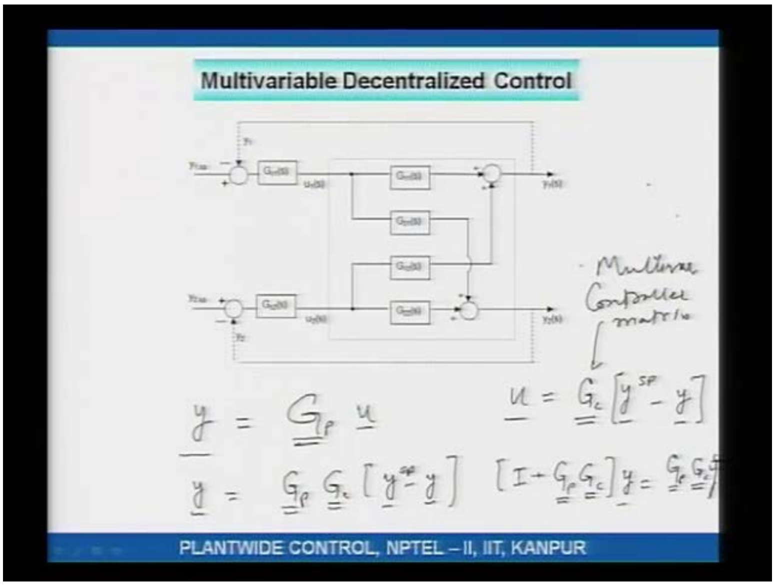

Now, so this is my multi variable 2 by 2 process and what I am now doing is controlling output 1 using input 1 and controlling output 2 using input 2. What we then have is this is actually called a decentralized control system and to understand this a little better, let me just say that what we have is y is equal to G p matrix times u. u being the input vector input. This input is error times a controller. So, u is equal to a control matrix time's error.

An error is actually y set point minus y measured. This is my controller controller matrix or rather a multi variable controller. If I substitute this over in the first equation what I have is output is equal to G p times G c both being matrices times y set point minus y. Now, if I take, if I collect the terms of y on one side and everything else on the other side. What I get is identity matrix plus G p G c times y is equal to G p G c, G t times y set point.

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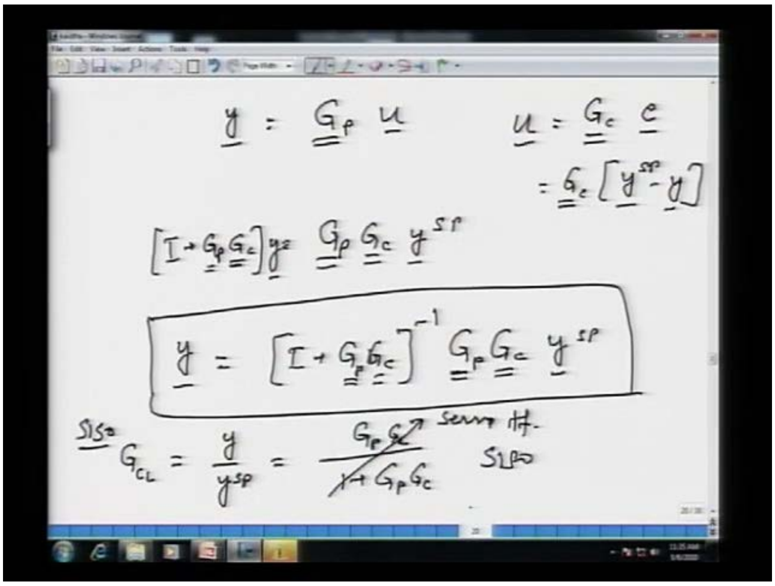

So, what I had was y is equal to G p times u and I said u is equal to a controller matrix times the error which is equal to controller matrix times definition of error is y set point minus y. Now, I substitute it there, what I get is I plus G p G c is equal to times y is equal to G p G c times y set point and what that essentially means is y is equal to I plus G p G c inverse times G p G c times y set point. By analogy if you remember your c's single input single output system, what you had there was the transfer function G closed loop is equal to for a SISO system single input single output system what you had was G closed loop that is equal to y divided by y set point which used to turn out to G p G c over 1 plus G p G c.

And this used to be, we used to refer to this as the servo transfer function, servo transfer function for a single input single output system SISO system. Well for a multi variable system you have something similar in the sense that you have got G p G c and since you cannot, there is nothing like a denominator in multi variable system what you have is the inverse of a matrix I plus G p G c is equivalent to 1 by is nothing but the inverse of 1 plus G p G c. Notice that for this for this multi variable system the order of multiplication it has to be G p G c and not G c G b because in matrix for scalars A times B is equal to B times A, but in matrices matrix A multiplied by matrix B is not necessarily equal to matrix B multiplied by matrix A. So, you have to take care of the ordering of the matrices, but this is essentially the equation that describes how the output changes, this is the servo multi variable equation.

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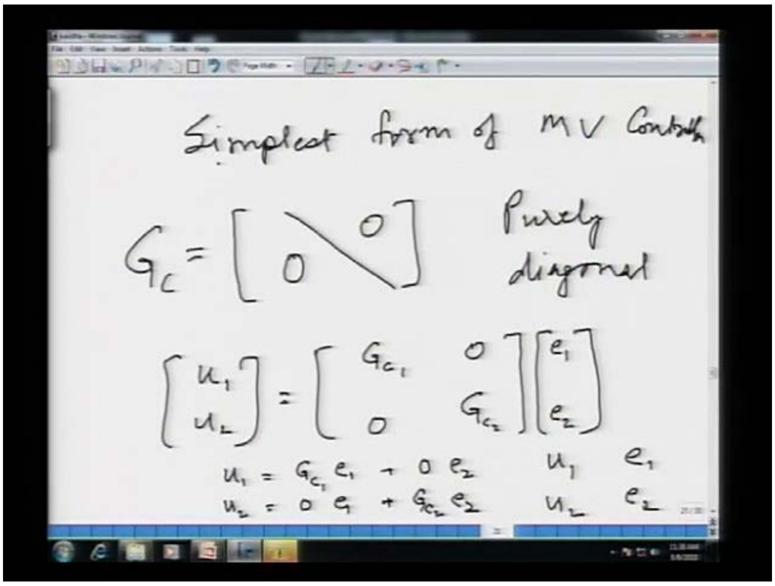

Now, the simplest G c simplest G c simplest form of the controller matrix, simplest form of the multi variable controller, what is the simplest matrix that you can think of? Simplest matrix is a diagonal matrix and nothing else here. Well this simplest you know purely diagonal, what that essentially means is when I have a purely diagonal controller what that means is u 1 u 2 is equal to some diagonal term here, let me call it G c 1 nothing here, nothing here G c 2 times error in 1, error in 2, this is my control equation.

Now, what is happening here is how the amount I move u 1 based only on e 1, I mean what what this equation is essentially saying is u 1 is equal to G c 1 e 1 and u 2 is equal to plus 0 times e 2 and u 2 is equal to 0 times e 1 plus G c 2 times e 2. What this equation essentially is saying is the movement in input 1 is governed only by e 1 and the movement in u 2 is governed only by e 2. That means I do not care what is happening to the other variable. I make changes here based only on this and I make changes there based only on that, this is essentially what is a decentralized controller, which was shown to you and I am going to show it to you again.

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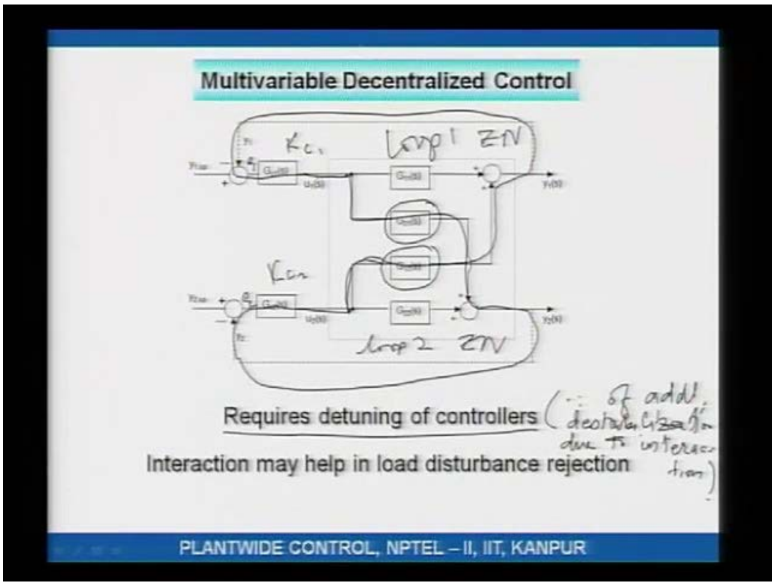

So, u 1 is changed based u 1 is changed based totally on e 1, u 1 depends only on e 1, u 2 depends only on e 2. So, this is a multi-variable decentralized control system and while what is done to u 2 is to bring y 2 back to set point whatever I do to u 2 disturbs y 1. Because y 1 gets disturbed my controller causes u 1 to change so that y 1 gets brought back to its set point. Whatever I do to u 1 affects y 2 and because now y 2 has been disturbed by u 1, my second controller adjusts u 2 to bring y 2 back and this adjustment in u 2 causes further adjustment in u 1 and so on so forth. What you see here, what I have, what has been drawn in this lousily drawn in with with the black pen is that interaction these interaction terms if they are non-zero, if these interaction terms are non-zero there is an additional feedback loop, there is an additional feedback loop that is that gets formed because of these interaction terms.

Suppose, these interaction terms were not there if these G 2 1 or G 1 2 or both are equal to 0 then you will see that this loop gets broken. So, interaction actually creates additional feedback and this additional feedback destabilizes your control system and in order and what that essentially dictates is you will require detuning of controllers because of interaction, because of additional destabilization, destabilization due to interaction due to the interaction terms, but interaction. So, this is one thing that needs to be realized about multi variable systems that the interaction actually dictates that for example, if there was no interaction if it was a SISO systems I would tune loop 1. So, this is loop 1, I could tune loop 1 using Ziegler-Nichols and I could tune loop 2 using again Ziegler-Nichols tuning.

What I was saying was that because of interaction you get additional destabilization because interaction causes an additional feedback circuit in your process and this additional feedback loop actually causes further destabilization and therefore, you would require detuning of controllers. What that means is if I add a simple SISO systems y 1, you know y 1 being controlled using u 1 and y 2 being controlled using u 2 with G 2 1 and G 1 2 being 0, I could tune loop 1 using Zeigler-Nichols setting using a, for a fast and snappy response. Similarly, I would tune loop 2 using Zeigler-Nichols settings Zeigler-Nichols settings for a fast and snappy response in y 2.

However, if there is interaction and I implement Z N settings in both the loops then what happens is both the loops are very tightly tuned individually. Now, because of the interaction what you would find is that if I implement those tunings my whole control system would either be unstable or would continue to oscillate or you know the oscillations would take a very long time to die down.

This is what this feedback due to additional inter, due to these interaction terms would do and in order to suppress those oscillations, in order to back off from the words of instability what that requires is you cannot use Zeigler-Nichols settings you will have to reduce the K c in this PI controller and the K c in this PI controller. So, detuning becomes necessary however note that you know interaction can sometimes help in low disturbance rejection. Given that in a multi variable system y 1 cannot be controlled as tightly had there, had it had it been a compared to a SISO system.

Now, because this because the system is multi variable y 1 will have you know you know the control of y 1 will have to be slightly loose or loosened enough such that, so you will require looser tuning.

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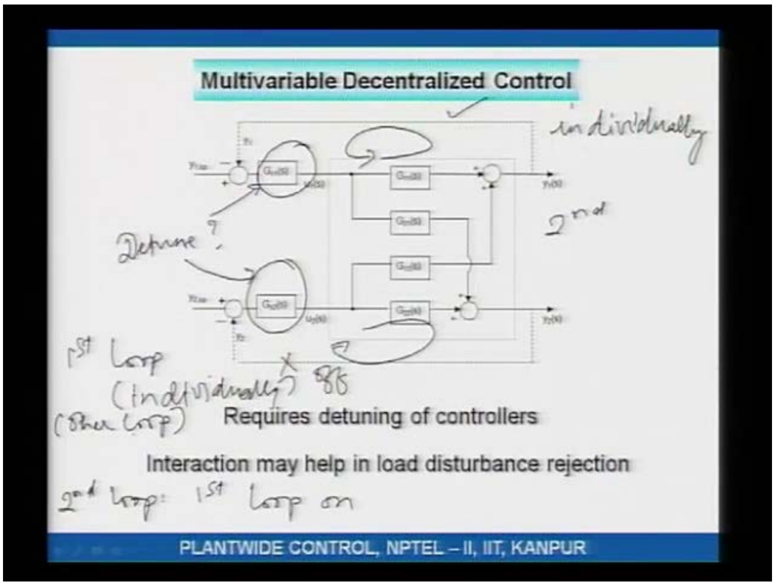

Now, what happens is now the question is how should you detune this, this meaning detuning is necessary, how do you detune this, detuning by how much and by how much should you detune this controller. That is the basic question that well in many situations what happens is controlling y 1 tightly may be much more important than controlling y 2 tightly. Many of our situations will boil down to okay I need tight control of y 1 as long as y 2 is controlled loosely it is okay as long as y 2 does not go out of bounds it is alright.

So, in such situations what you do is, you switch off this loop, this loop is off, that means the feedback loop connection is not not made, tune this loop individually. Where you desire tight control, that loop is tuned individually with the other loop of really tight. Once this loop has been tuned, you will get a very fast and snappy response in y 1, to tune the other loop keep this loop on and then tune this second loop. So, second loop is tuned, first loop is tuned individually first loop is tuned is individually, second loop the less important loop where control is, tight control is not as necessary or as tight control is not critical, is not critical or crucial, the second loop is tuned with first loop on.

When I say first loop is tuned individually that means other loop is off, if you follow this procedure for tuning what you will find is that all of the detuning is taken in the second loop. You see what I am saying. So, all of the detuning is taken in the second loop, first loop is tightly controlled that would give me acceptable control performance. What if both the control objectives are relatively equally important, well that gets slightly technical and maybe we will cover this in the next couple of lectures, for that some some amount of theory is necessary, and we will do that may be in the next couple of lectures with that I think, I would like to end this session here. Thank you very much.