Switched Mode Power Conversion

Prof. L. Umanand
Department of Electronics Systems Engineering
Indian Institute of Science, Bangalore

Lecture - 29

Good day to all of you, last class we were discussing on the PID controller, we had discussed be proportional part, the integral part and also touched upon the derivative part. We shall continue with the discussion on the PID controller this session also, and see how that derivative part affects the overall frequency response of the controller.

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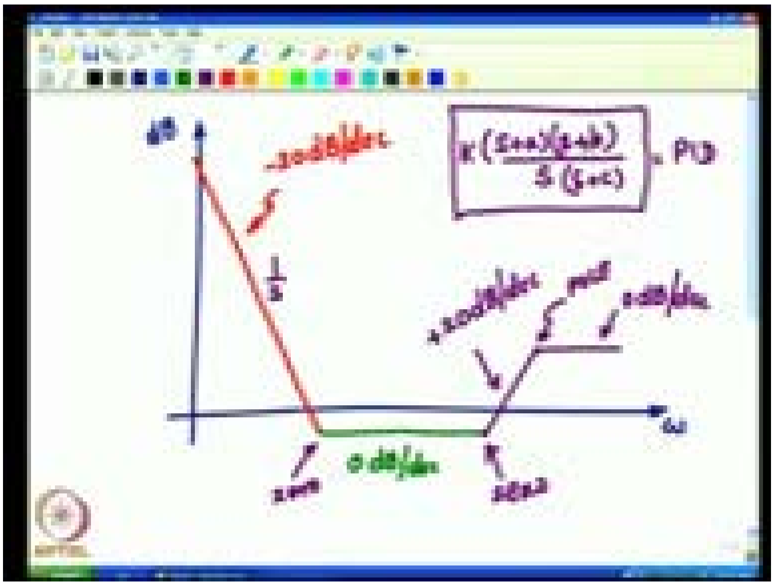

If you recall, let us say we have omega verses the d B gain the integrator the i portion has a slope minus 20 d B per decade falls at this rate. And then comes the derivative, a proportional parts where the slope becomes 0 dB per decade. Then you have another change of slope plus 20 dB per decade and again flat at 0 dB per decade. So, if you see minus 20 dB per decade 1 by s there is a pole and here you are adding 0, a 0 comes into the picture. So, let us say a pole then as 0 comes into the picture, then one more 0 comes into the picture at this point, and then a pole comes into the picture here.

So, transfer function of the PID controller will be something like this, to look like this PID controller transfer function with an associated gain K, consolidated gain K. In the previous classes, we saw the frequency response plot in mat lab of the integrator of the proportional part included and the last towards the end, we discussed the introduction of the derivative part, which is one extra pole here and a 0 a coming to the picture.

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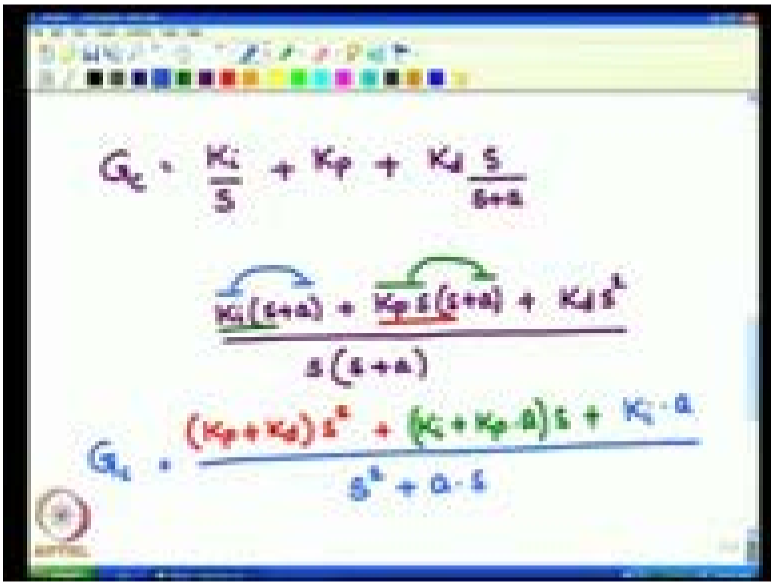

So, let us see how do we introduce the derivative into the PID controller structure. So, till now we had the integrator scalar scaling by S plus K p a proportional gain plus, now we shall have a derivative scaling gain scaling into the derivative caution s, but that as this we cannot implement by itself not physical system.

There will be a pole a lag component and this is the last portion of the last portion of this frequency response here the high frequency portion that is get a reflected here due to the pole. So, this is a transfer function, so if we converted into polynomials numerator and denominator polynomials. So, would get S, s plus a so K i s plus a plus K p S into s plus a plus K d s square, so this would be the numerator portion.

So, if you expanded and then take we powers of s you will have K p plus K d S square plus, you will have S to the power of 1 functions. This with this, so you will have K I plus K p into a S plus it is chosen other color blue you have this along with this as the 0 the power K I into a hole of this is divided s square plus a S plus 0 or we could just leave it in this form. So, this would be the transfer function G c for the entire PID controller.

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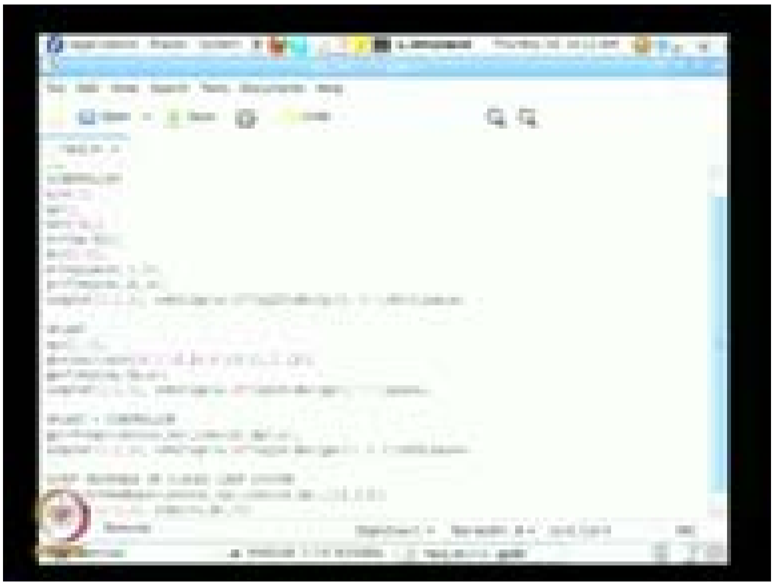

Now, we let us incorporate this into the mat lab let me switch over to the mat lab. Now, in mat lab, we have the mat lab work space and I have the file that we had yesterday in the last class. We need to which has the controller recall that you have a controller portion you have the plant, which we are not changing. We use the same plant, we have the plant plus the controller the frequency response of that and then we have try to plot the step response for the close sloop system using the feedback comment.

So, let us now focus our attention to this part that is a controller part we have one more degree of freedom K i is the gain for the integrator K p is the scaling proportional scaling. We include one more, which is K d. And let us give a small value for the K d scaling, now what is the numerator polynomial, so the numerator polynomial is in this form.

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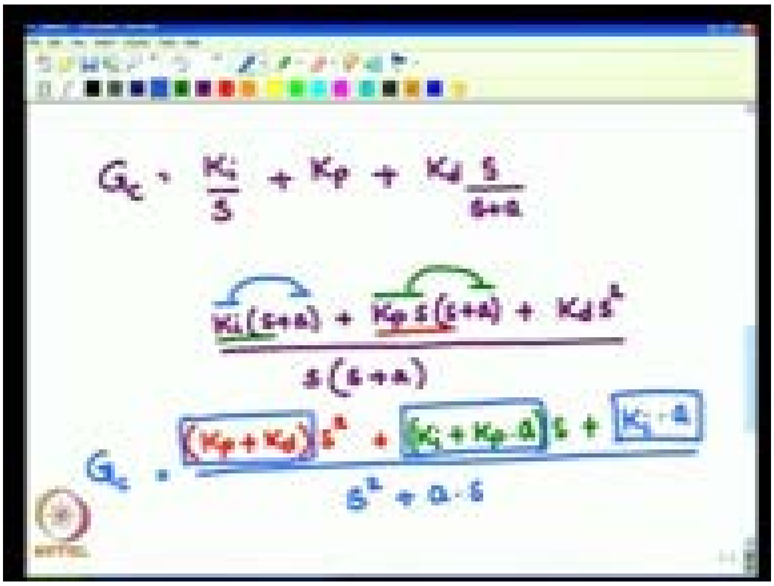

If you look back to the white board, the coefficient of a square is this, the coefficient of s, and the co efficient of s to the power of 0. So, we shall write that so n c would become the numerator polynomial would become, so we will go back to the mat lab. The numerator polynomial would K p plus K d us the power of a square then the next term would be K i plus K p into a. And a, is something that we need to define and the S to the power of 0 term would be K i into a.

Now a is the pole which is the further removed pole, so let us keep a for now at, a equals let us say 1000, 10 power 3 or may be slightly lesser. So, that it comes into the space of let us try by first giving 800 and then see how what happens. Then the denominator polynomial becomes 1 that is S square a s plus 0. So, this, the equation that is this is a controller a numerator and denominator polynomial.

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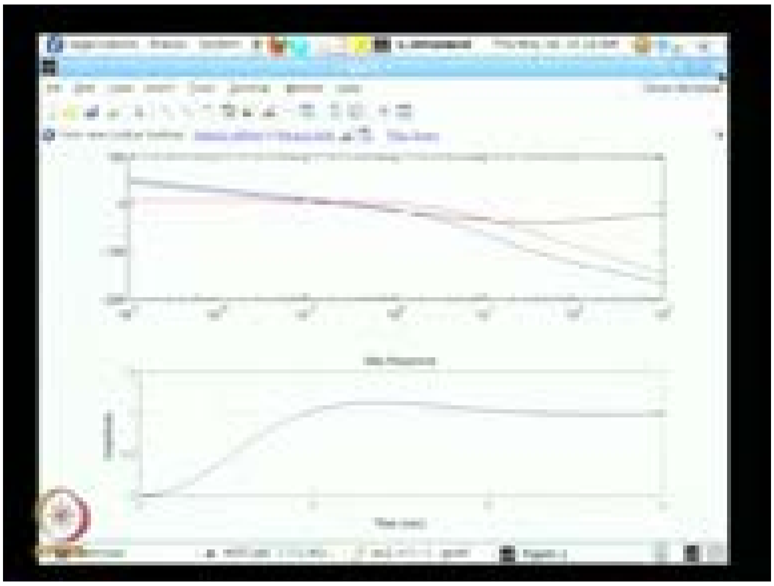

We have given some samples values here and let us execute in mat lab x 1 the same file and see what happens. Now, here you have the integrator and let me this is not too visible, let me change the values to make it better visible. Let us go, let us remove the make the effect of K p small 0 1 and may be make the effect of K d and it more let us close the window re execute e x 1.

Now, here we are able to with the changed parameters, you let me expand this you see here the integrator after this you have that attenuation and some were here at 20 the proportional part of the controller is introduced. It changes the slop makes it flat and then some were at this point the derivative part of the 0 comes to the picture, changes the slop and then some were here at 800 we saw we given is s 800 you see again in change slop were it rise to go further. So, that would be the plant and along with the plant you see the blue line this would be the modified plant and controller frequency response and then the time response.

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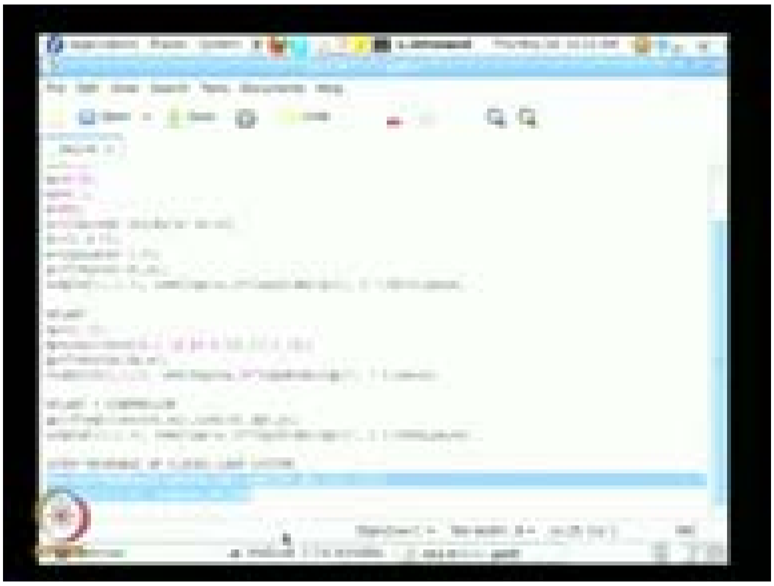

Now, at this point let me try to tell you few points here this is the controller transfer functions that we have been seeing if you want to see an expanded scale frequency, you could change the number the range of the x access frequency here at this point from 10 to the power of minus 3 to 10 to the power of 3 it could be made 10 to the power of 4 and that omega will be used for all the other plots too.

And one could also if, so desired can see the face plot also I will show that a bit later that the face plot will actually complete the frequency response plot. Now, for, now to get a better understanding let me, let me remove the plot, which the sub plot that we have we use seeing of the plant. Because the plants of plot is now fairly well in grain to the mine we will see the plot the frequency response plot of the controller and the frequency response plot of the controller plus the plant. So, that it will not clatter of the space then the frequency then the step response of the close slop system, so this plots we could have a look at let me save this got the mat lab out space x 1.

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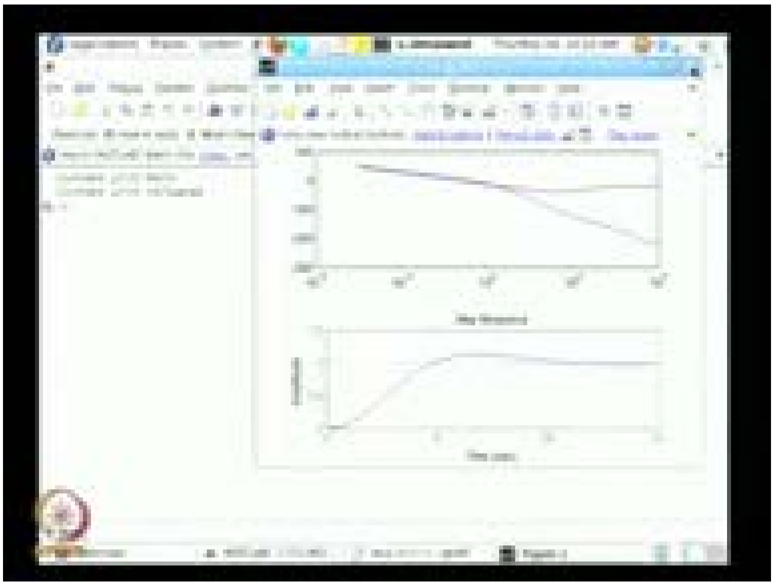

So, you see these plots here. We have a expanded, we have seen an the x axis scale expanded and you are, now able to clearly see the change in the slop due to the of final pole this is a typical frequency response characteristic of PID controller.

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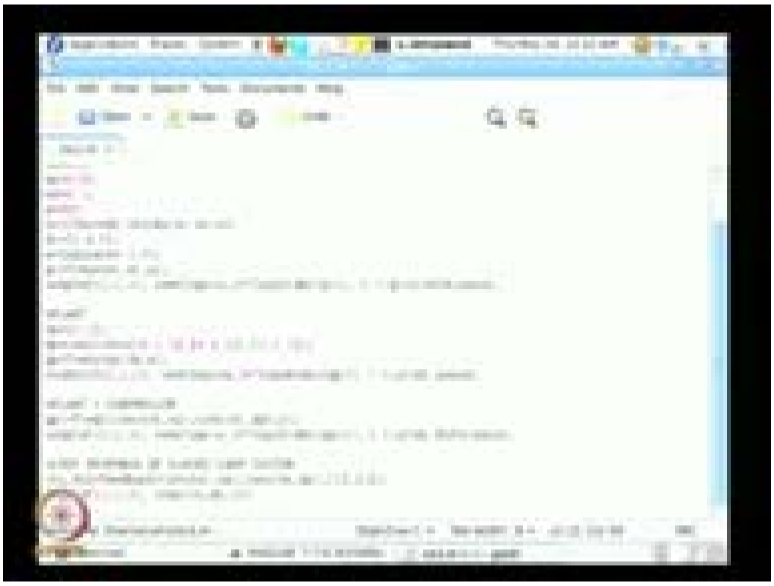

And along with it, now here you are seeing the three controller plus the plant together and then the time response there are few more things that you can add to get a bit more information you can add the grids to this. And x label and the y label if necessary, what we will do here is for all this plots we shall give the grid, so this will make the plots are bit more easy to understand.

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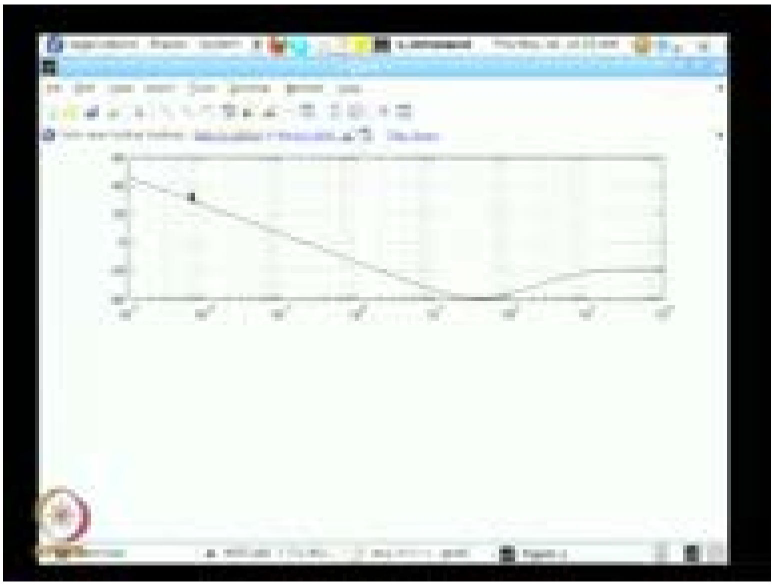

So, let us expand this. Now, here we see this is the same old PID controller of frequency response that we have been discussing till now this is the integrator part falling at minus 20 V per decade. Now, I want you to bring, I want to bring your attention to this line 0 d B. Line, now the 0 d B line represent unity gain when do you get 0 d B the log of 1 log to based 10 of 1 is 0. That means for a unity gain you will 0 d B anything less than 1 that is a between 0 and 1 the log of it is negative, so that means attenuation all the values here imply gains, which are less than 1.

All the values which are above 0 imply gains greater than 1, so what we are actually trying to do is pull up the plants gain at the lower frequency. We increase we try to increase the plant gain at lower frequency are study state region such that the error is 0. And the plant gains at the higher frequency side is brought down pull down such that it is less (( )) state in nice and that is basically effecting the traction portion of the response you are defiantly going to have error. What is under your control is how fast the system comes to the study state portion? The movement there is a disturbance the system is immediately in the agitated region is i frequency region.

Then it starts traversing through the frequency to words the 0 or d c and into the study state portion how fast are how quickly the system traverses to the study state are d c portion is what we have been trying to address in trying to adjust the high frequency gains. By the p and the d you see this is the derivative portion this is the proportional portion. So, the movement there is disturbance the system immediately goes to the high frequencies zone were the derivative is per dominant the derivative hands over the battened to the proportional part. The battened is handed over to the integral part seem rashly and a integrator handles it all along to words the study state zone, now let us come over to the white board and have a look at some of the concepts.

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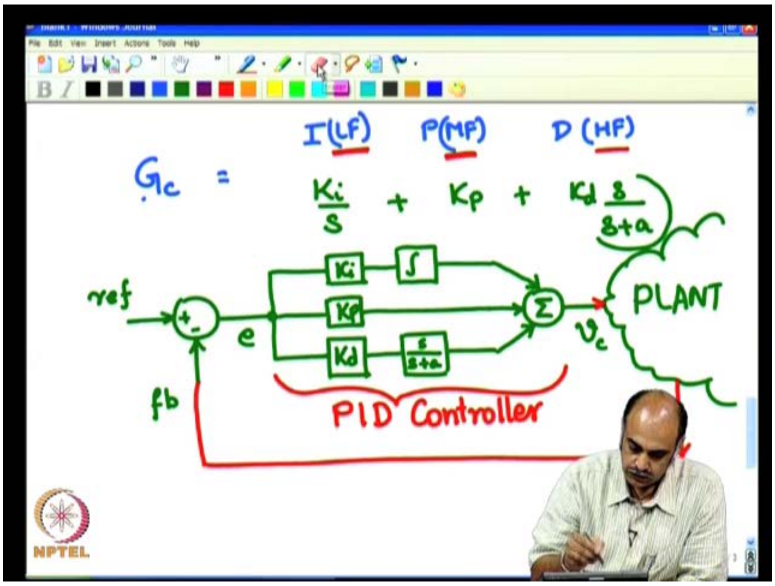

Now, here if you see G c is having three parts the integrator part the proportional part and the derivative part. Consciously I am putting it in this order this is to indicate that this is the most H F this is medium frequency, this is low frequency. The D part is effective during high frequency in the high frequency portions of the frequency response proportional part is effective in the medium frequency portion. And the integrator the effective in the low frequency and the study state portion and we have the transfer function in this form, so block diagrammatically if you want a represent the error.

So, let us say we have the error e this is the reference and you have the feedback the error e passes through 3 components the first one is the integrator. Let us say K i an integer the second one is just plain proportional gain just a fixed it gain. And the forth one the third one is oppose to be something like this K d into derivative, but normally you can make a derivative. So, you take the first order approximation or the second approximation and therefore, you have something like that therefore I shall a write a more practical derivative like this and then at this end all are added up sigma summed.

And the consolidated control old age actually goes to the plant and we take the feedback from the plant this is the control input and a feedback from a plant is use for comparison with the reference so this the structure of our PID controller the block diagram structure of PID controller this portion is called the PID controller. Now, there are just a block structure of a PID controller there are few issues that you should understand during implementation and there pretty important significant in its effects on the plant this system.

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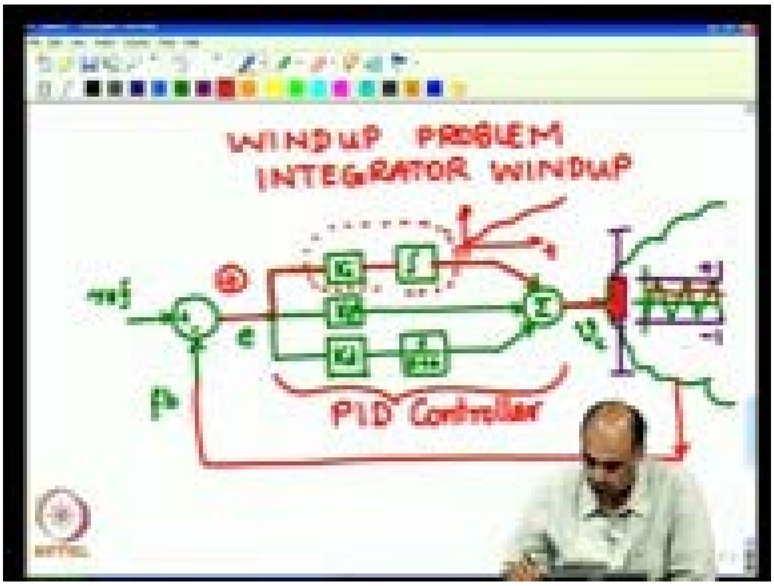

So, let us clear out some space, so we have the controller in this passion. Now, assume that the error is positive, error is positive. So, once the error here is positive the problem right, now I am going to discuss is more focus in this region integrator the problem that I am going to explain discuss. Address is called the windup problem on the literature it is also called integrator windup, so what is this windup problem let us consider only this portion of the controller assuming that this other 2 portions do not exist. And even if they exist they will not contribute to this problem, now let us say that the error has gone positive when the error has gone positive the integrator keeps integrating the output of the integrator. This is an accumulator keeps accumulating and the value here keeps increasing monotonically with time.

Now, the plant at the front end here of the plant the input portion of the plant will have some interface circuitry and this interface circuitry will some voltage limit the voltage limits for interface. Circuit could be 0 to 5 volts it could be minus 15 volts to plus 15 volts 0 to 3 point 3 volts or any of the standards applies or it could be 1 less that these supply voltage for example, let us say the interface portion. Let, us say that the interface portion consists of triangle and this V c comparison, so which means you have a triangle wave form.

And with this triangle waveform this V c is going to get compared to generate pulse fit modulation such is the case then this V c has a limit voltage which is the upper and the lower triangle tips if triangle voltage. Waveform is traverse minus 1 to plus 1 about hour the circuit suggested voltage V c imitated from minus 1 to plus 1. So, in the interface circuitry whatever be the value of V c it will get limited depending upon the interface circuitry within some voltage band. However, the error has still not change example V c has crossed over plus 1 once V c has crossed over plus 1 though the plant is responding to that it will respond to clamped value of the input it would gone into open loop operation.

The error here has not changed the integrator is still accumulating even though V c has gone beyond volts plant does plant input does not recognize anything beyond one volt. The integrator keeps on integrating because the error is positive and when the error the plant has taken some action and the feedback as change and the error goes negative. The integrator will take some time for it to wine down it has wound up for it wine down and then come into the control band. Sometime elapses before the system comes back into close loop operation this is called the windup problem. Let me explain this problem in more detail, with is simple waveform.

Now let us draw the waveform with respect to time. Now, let say this is a time axis and let me have one more axis again time axis and let us try to visualize parameters. One is the error and the other is the control voltage V c at the output of the controller. So, basically this is at the input of controller input of G c this is at the output of G c controller. So, keep that in mind visualize a block diagram which is like this K i integrator V c error error coming from reference feedback. This goes to the plant visualize the block diagram something like this and you are right now interested in seeing this the input to the controller which is nothing but, and output of the controller. So, keeping in mind a pure integrator with this kind of (( )) structure

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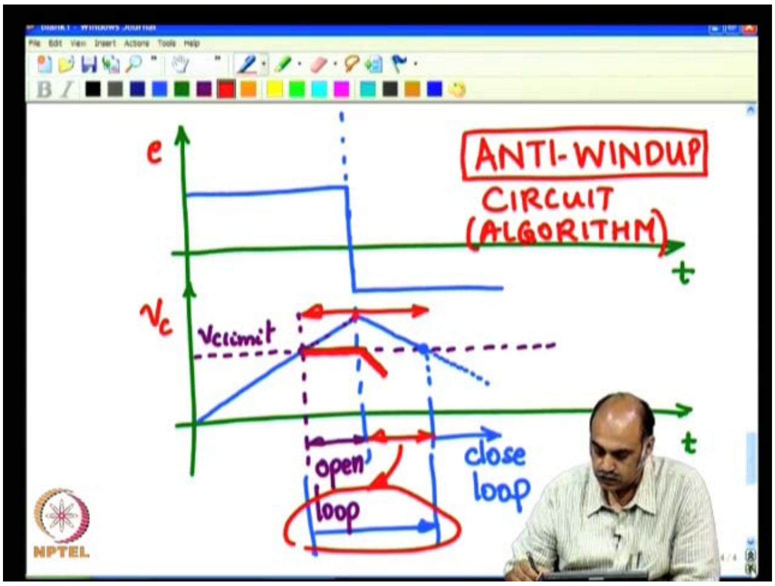

Let us see what happens let us say that the is positive and constant like this the output V c of the integrator. If you it will keep going in this fashion, now if it would not a constant it would still be some accumulating waveform which monotonically increases. Now, let us apply some constraints. Let us say the output of V c which is given to the plant is limited at this value. So this is the V c limit it could be the upper triangle tip in the case of the p w m modulation, so which means at this point itself the limit has occurred. And from this point onwards from this time point here the system is in open loop.

Because any change, change in V c the system will not respond because it is clamped to this point, but the integrator is free to integrate. It as accumulate up to this point here, now at this dotted line crosses time corresponding to this dotted line let us say the error has changed. Now, the change in error can be many can be can be due to many reasons, because the input is clamp to the upper extreme or positive extreme we plant will try to the plant output will try to increases and as it increases. The feedback value increases and tries to…

When it compares the reference value it may go negative at one particular point of time and that is when the error would switch negative, so this would switch negative once this switches negative. If you take the integrator it starts again as a coming down like this V accumulating, now at this point when it starts to enter below the V c limit, now that is where the close loop operation will command. That is when the system comes back into close loop, now till that point of time till that point of time including this red arrow mark it is in open loop whole system is in open loop.

The reason it has taken this much finite time is because it had accumulated it had wound up to this level. Now, it has to unwind come to this level and from then on the integrator would be within the control band and the system will be in close loop. Now, this is the wind up problem where this much amount of time, where this much amount of time the system is in open loop due to the integrator having wound up to a. A higher value than this element, now let us say that we want to solve that problem this wind up problem.

What is it that we want to do? What we would like to do is when it has reached this limit the integrator output the V c should not wind up, but it should go just at the V c limit clamp point just go along at this point. Then when the error has changed notice and when the error has changed direction the integrator will start the integrator will start into coming into the control band immediately. So, this way the system is not in the open loop it is at the boundary of open loop or boundary of close loop. And then the moment there error changes the direction it is within the close loop immediately, so you do not have this portion of time where the system spends in open loop loading the integrator wind up. Now, a circuit or mechanism that does this maintain the integrator or output at the boundary of V c limit or not allowing the integrator to wind up when the V c.

Limiter has reached such that the integrator can immediately jump back into action is called anti wind up circuit. If you are using as a circuit algorithm if you are using and algorithm to solve to this problem in the digital domain with in a micro controller, so this anti windup solution is important if you are using an integrator. And it is very, very significant in its effect because during a portion of the time the system is out of open loop. There is no control at all and it could very easily go out of the bounce of the specification of the product of the Equipment and (( )) damaged the loads or any other components connected to the system.

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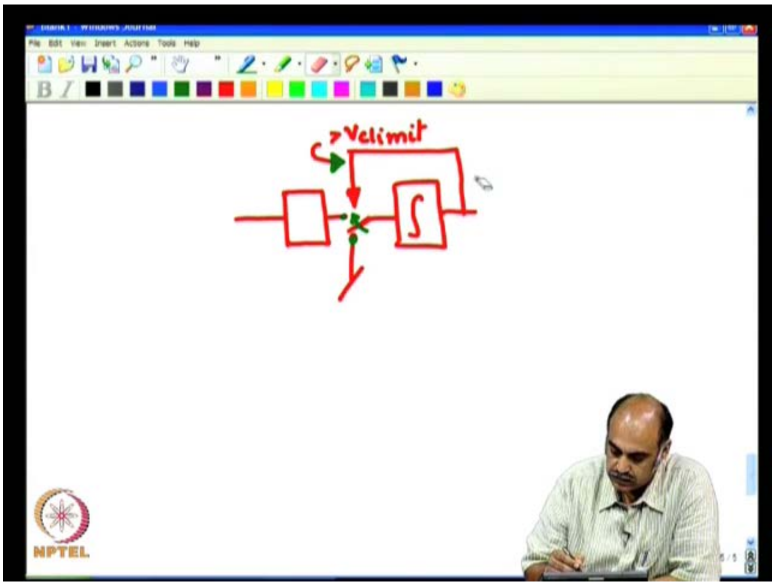

Therefore, anti windup solution is a must and must be concisely taken concisely included in the PID scheme of controller. Now, to do that when you use, whenever you use an integrator the integrator itself has to be limited where is you do not allow look at the output. Once it has crossed the V c limit you have some mechanism where it will switch, so once this control is greater than V c limit this value. This will switch this switch pole to ground which is 0 and the integrator will not accumulate any further the movement. Error changes and V c is less than V c limit or you have a change in error this will switch this pack here logically this what would happen, but in implementation wise there are many different ways which are done. And we will look at 1 or 2 which are used simple mechanism which is used in (( )).

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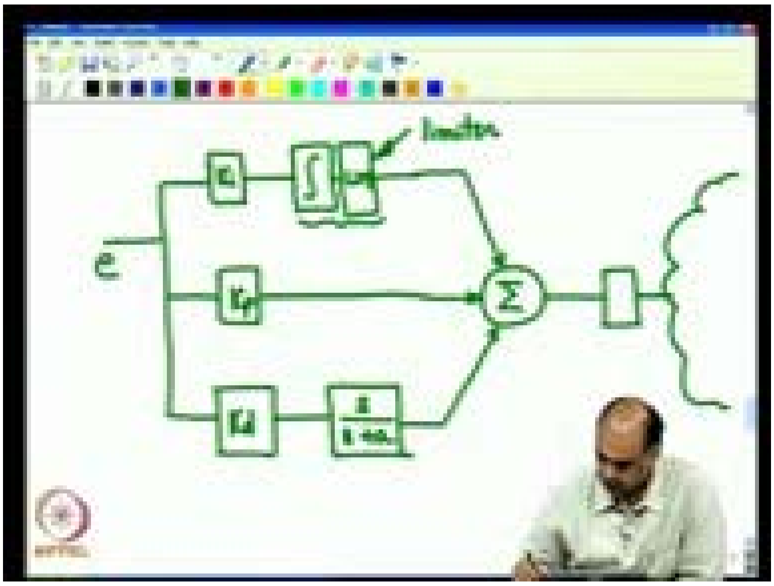

How do we implement the controller? One of the simplest way is to use the block schematic that we had error and try to duplicate that you have a gain K i integrator K p K d. And a summer like this you need to have for the integrator limiter which co-exist with the integrator, such that the integrator does not wind up. You could also have a limiter here to because this voltage has to be compatible with the plant input which is actually the sum of the integrator output. And the proportional output and the derivative output, I am sorry missed out the derivative part here.

So, it is like this, now let us take up first the integrator portion we can implement all this using opals and let us try to do that. You will need, let us say the first solution would be the one which does not optimize on the number of opams. We will need let us say and opium for this gain and opam for integration 1 opam for this gain and opam for this gain. And this low past filter the filter effect and then summing I Approximate Methods, so, an opam for reach of this blocks.

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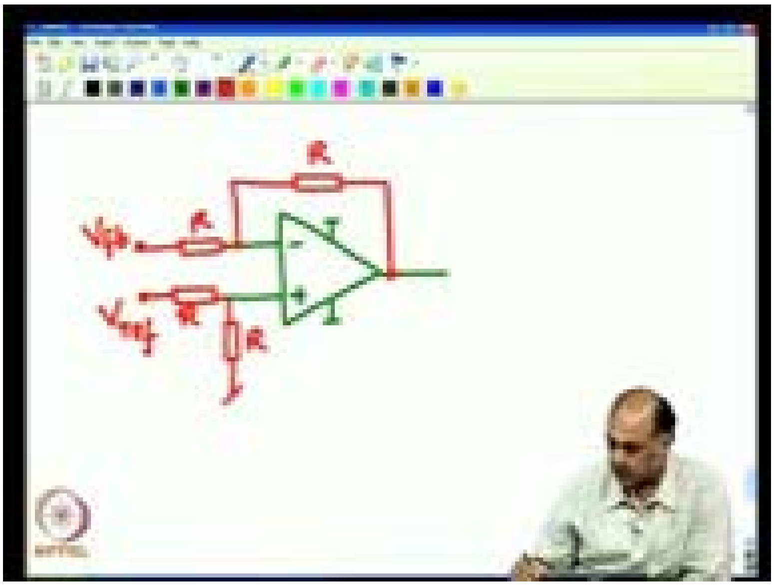

So, let us see what is type of the circuit that you will come up with take for example, and opam plus minus. And I am assuming the that we have the force apply pins to the input pins and 1 output pins this is the opam, now to the opam to the opam if you connect 2 registers in this fashion and 2 more registers in this fashion.

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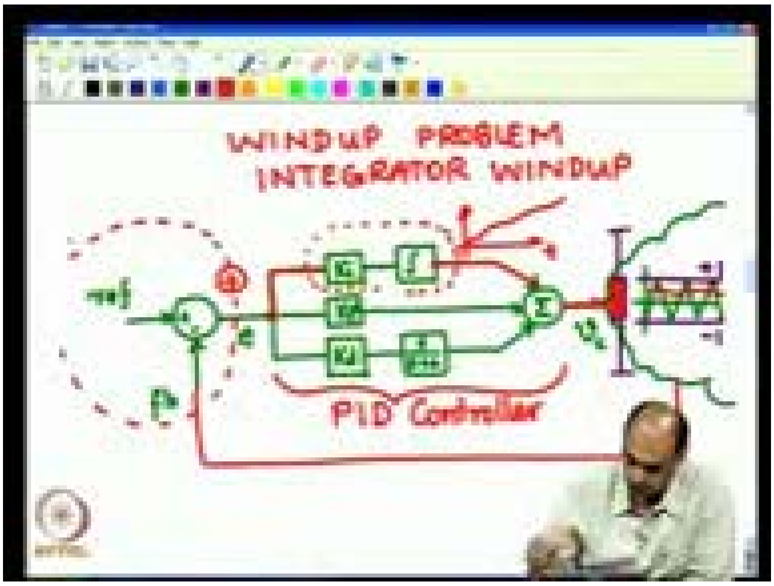

You and let us say the royal equal to registers are R and R, so let say this is V reference.

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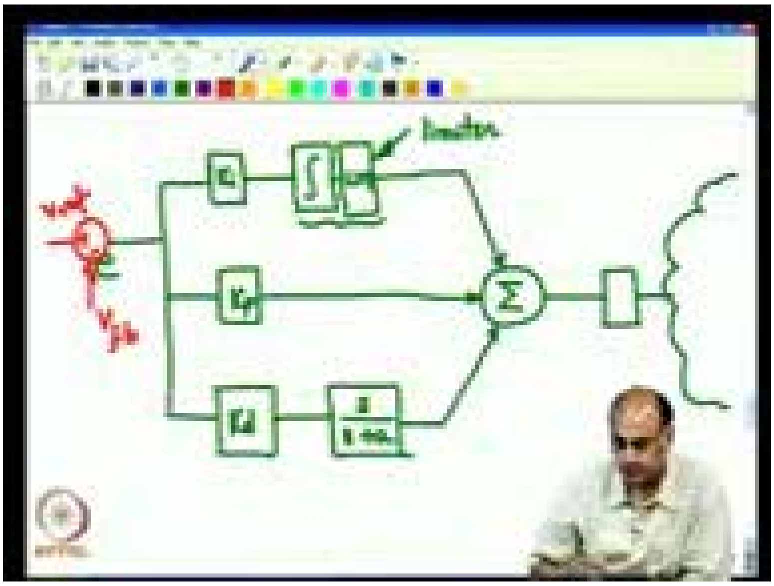

This is V feedback which corresponds to the to which corresponds to this portion of the circuit. If you want to indicate it here it corresponds to this portion V ref plus minus.

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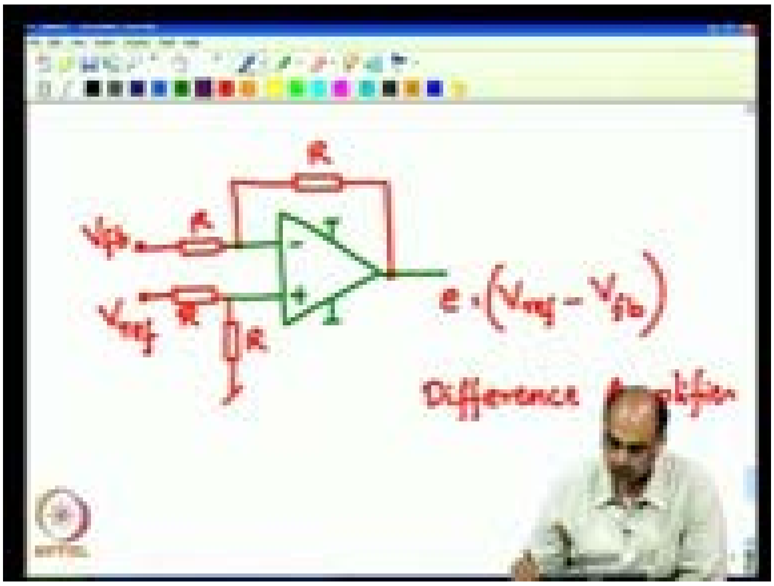

Now, that will give you and output called e the error which is equal to V ref minus V. Feedback, so this is the difference amplifier which is used to get this portion of the circuit the comparator portion of the circuit V rest minus V f b. Now, from the error next let us get the integration and action

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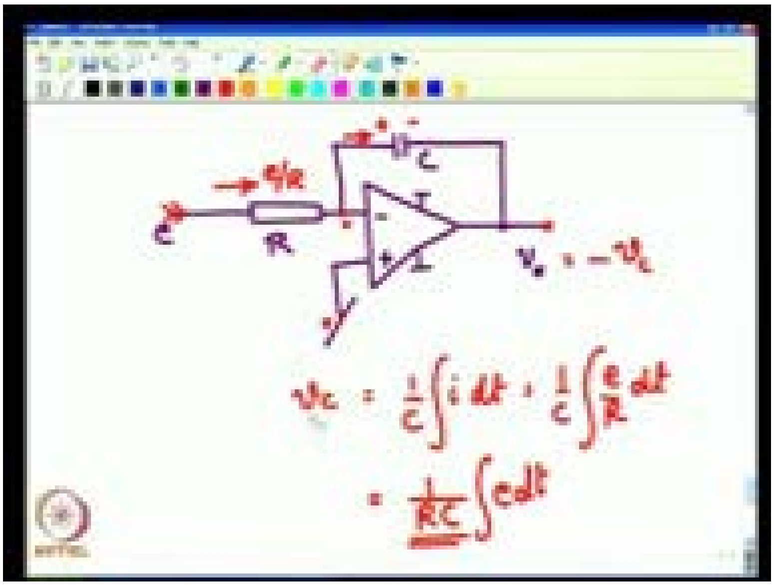

So, from the error which is coming from the previous part. Let us say V pass minus plus, now this we will ground it through this capacitance in the feedback path. So, let us say V V naught this is R and this is c, now this potential is this is grounded 0 this potential is 0. So, you have a current e by R which is flowing through this and therefore, through this so the voltage V c across capacitance is like this because the current is charging it up in this way positive. And that would be equal to 1 by c integrator of I d t which is equal to 1 by c integral of e by R by r d t which is nothing but 1 by R c integral of e d t and that is what we want integral of the error.

Off course is it is getting scarred by 1 by R c now this is the voltage across the, now you want the voltage at V naught here. So, this end of this end of V naught is connected, the negative plate of the capacitance the positive plates capacitance connected to this point which is at virtual ground, so V naught will be minus V c. So, what we have for V naught V naught is nothing but negative of minus 1 by the integral of the input voltage in this input voltage in this case the error voltage.

So, this is part V actually wanted to have now this is just only plane integration with this amount of that we need to have flexibility in scaling scaling the e integrator output. So, let us say we connect that output to 1 more opam to 1 more opam in this fashion and that is V naught, now here your getting let us say minus V c now that minus V c this is an inverting amplifier it would become let us say this is R 1 and this is R 2.

Now, the gain is minus R 1 and R 1 by R 2, so V naught is equal to minus its input minus V c r 1 by R 2. This is, let me right it clearly V naught is equal to minus the input voltage which is minus V c r 1 by R 2. This would be the output here and here, output of the final integrator plus gains scalier.

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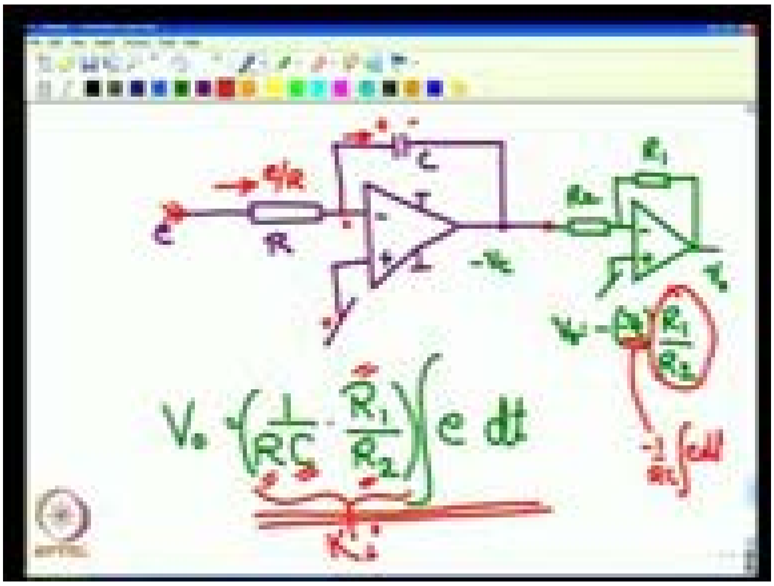

Now, if you input minus V c, it would become… So, replacing for V c for which is minus 1 by minus V c which is nothing but minus 1 by R c integral of V d t and including R 1 by R 2 gain you will get the output of the integrator scalar as this. This is a constant, this is a constant, this is a constant, this is a constant. However, you have control and choosing all of this. Therefore, this can be consider as K i and you can opertely choose that the value of K i however in practice we do not use too many. Opamps will be we will be optimizing number of opamps later on, but let us get the first cut circuit without putting a limit on number of opamps. So, we will stop here for today and continue in the next class.

Thanks you.