Power Systems Dynamics and Control
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Lecture No. # 27
Excitation System Modeling Automatic Voltage Regulator (Contd.)

We are now in the 27th lecture of this course; and we are focusing on the modeling of the automatic voltage regulator, just to you know view things in perspective, we have modeled two kinds of power apparatus in this course. One is the synchronous machine itself, and also the excitation system, which feeds the field voltage to the synchronous machine. Both of these are power apparatus, we the dynamical system is also contributed by the excitation system controllers, and the primary function of the excitation system controllers, which are in fact feedback controllers which are made by us is to regulate the voltage at a terminal of a synchronous machine.

We saw that if you look at the block diagram of a excitation system controller, we also saw that we can implement other functions like improving the stability of you know, the electromechanical system, this is something we have not shown yet, but in general and excitation system can also provide for this function. And also it can change the field voltage if certain limits are hit; for example, if the field current limit is hit or later on we will see that if the load angle becomes larger or delta becomes larger of the machine, then also you can actually change the field voltage and try to rectify this situation.

So, in today's class, what we will do is consider certain further transfer function blocks, we were discussing transfer function blocks, which essentially make up the automatic voltage regulation system in a synchronous generator excitation system. The transfer function blocks we have considered so far are the simple first order transfer function and also wash out circuit; both these blocks are very essential and important in the discussion of any practical control system.

Remember, that we are talking of a transfer function block diagrams, because you will find that most of the representation of the control systems will be in this form. So, if you will open the manual of a synchronous machine in real life you will find it, you know the nature of the AVR etcetera is expressed not in terms of state space equations or differential equations, but in terms of block diagrams. So, we have to interpret the state space relationship or the mathematical functions in terms of what is given to you in block diagram. So, today we will continue that; so today's lecture is continuation of our discussion of the automatic voltage regulation. We are really looking at a few transfer function blocks.

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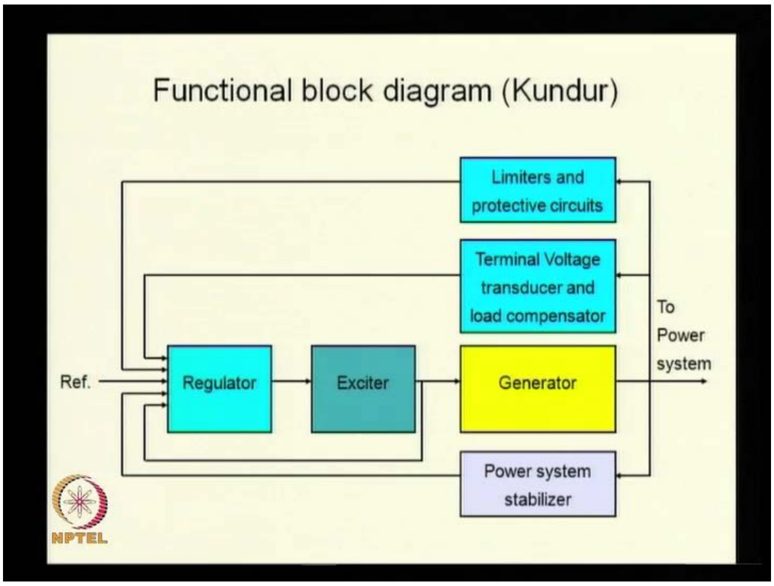

So, the first transfer function block, which we will discuss, pertains to the regulator.

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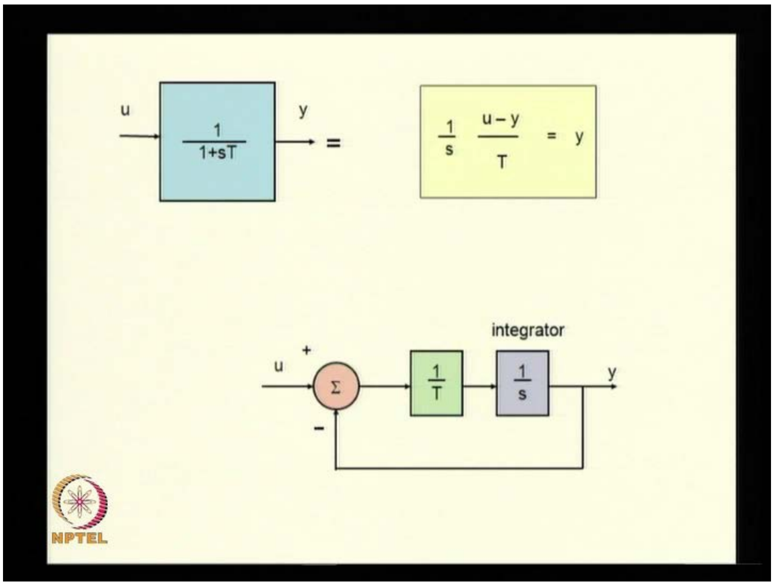

In fact, what we did was in the previous class was in fact a first order transfer function block, whose block diagram is represented by the figure given at the bottom, and the transfer function represents or rather the state space representation of this is given by this.

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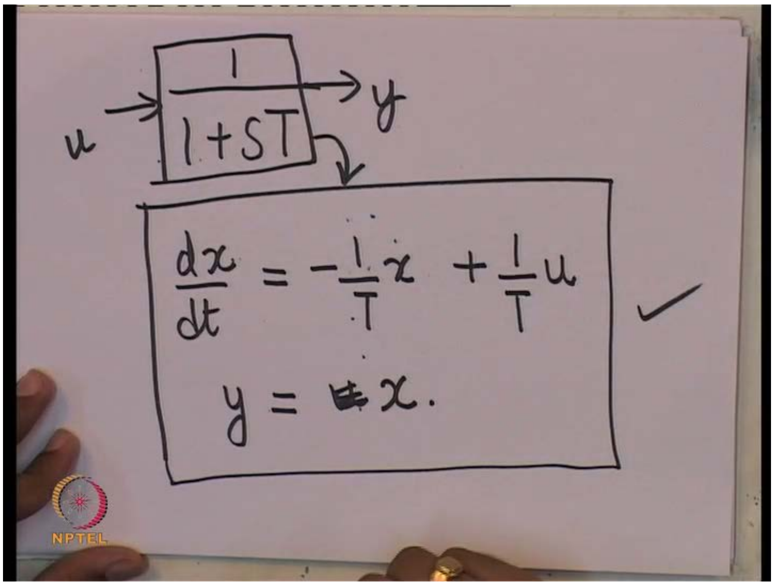

So, if somebody gives you 1 upon 1 plus ST you should write it down immediately like this. There is no unique state space representation of a transfer function. Also, if you give, you have given a transfer function like this. It also means it is a linear system; it is a linear time invariant system. You can actually add some complexities to the transfer function block diagram which make it linear for example, non-linear for example, we could have limiters etcetera, which we will discuss shortly.

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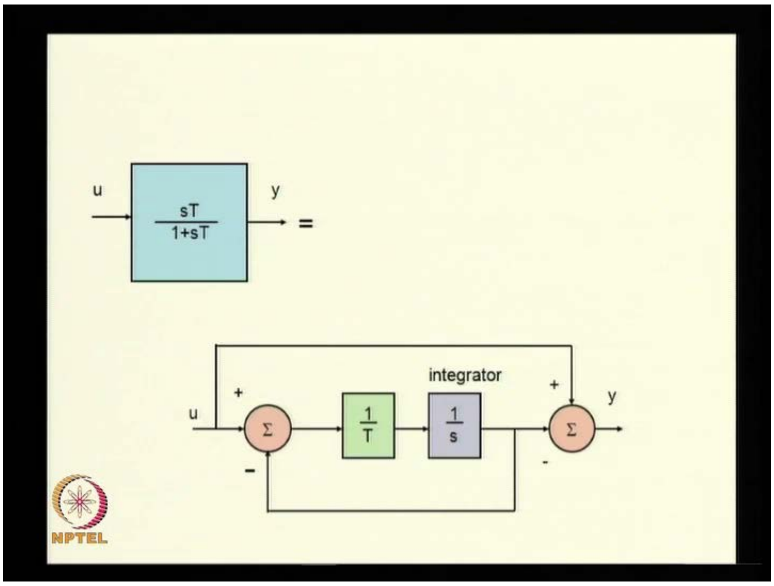

The second transfer function, which we discussed last time was in fact a wash out circuit; this is in fact a system which is represented by the block diagram which is given below. The block diagram is kind of expanded, but remembers it really the block diagram is a manifestation of the state space equations which are given here on this, on the sheet. You will find that there is a minor difference between the block diagram given previously and the block diagram given here. In terms of its complexity, but the functions can be in some sense opposite of each other.

Whereas, the first order transfer function block here has got characteristics of a low pass filter, the wash out block here has got the characteristics of a high pass filter. In the sense, that this is got a unity gain for high frequency and 0 gain for low frequencies. So, it is essentially used in situations where you want to pass through transients, but you want to block, you know any offset or steady state input.

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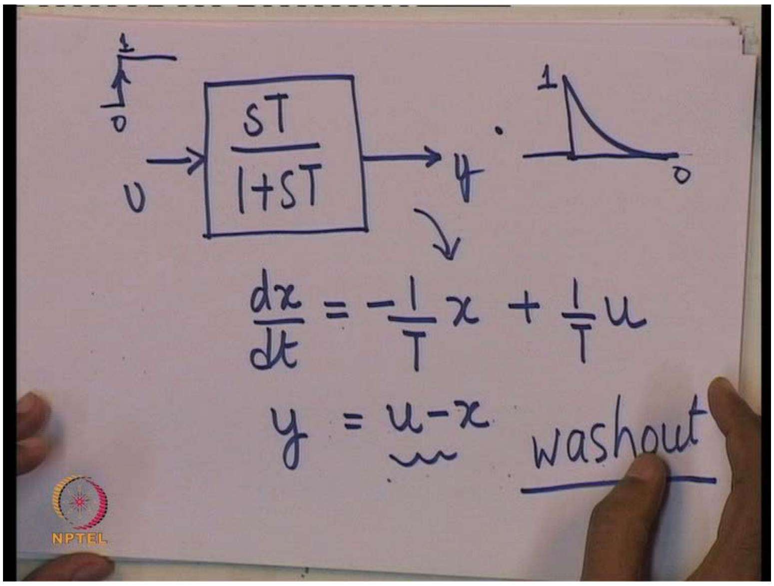

Now, the state space representation of this block diagram is as given on the sheet here so, you can have a look at that. We derived it in the previous lecture, again there is no unique representation state space representation of this, but this is the most common representation you will find. The step response of this transfer function is like this, in steady state if you give a step here in steady state you will get a 0 here eventually whereas, the transient gain is one.

So, as soon as the step occurs this also responds. So in this sense, this particular transfer function is different from the previous one of course, these are transfer functions you will encounter, but as I mentioned sometime back the regulator transfer function is usually slightly different, it does contains these blocks sometimes, but the main regulator function of course, is to drive the error between a set value and the actual value to 0.

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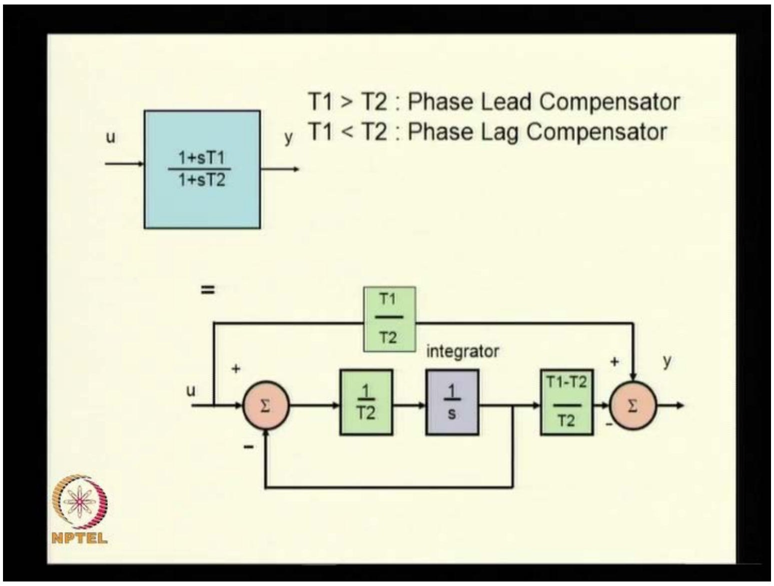

So, what are regulator transfer functions? We shall see shortly. But before we do that we will just look at one more transfer function which is very important, and that is 1 plus sT 1 upon 1 plus sT 2. Now, this is another transfer function which you can which you will encounter very often in practice in fact, if T 1 is greater that T 2 the numerator time constant is greater than the denominator time constant then it is known as phase lead compensator, you will find that if you give a input u which is a sinusoid then in steady state y, which is also sinusoid will lead the input u that is if T 1 is greater than T 2.

So, the block diagrammatic representation is of course, given below here, so this particular compensator it could be a lead or lag compensator depending on the relative values of T 1 and T 2 is a transfer function which is encountered quite often in practice.

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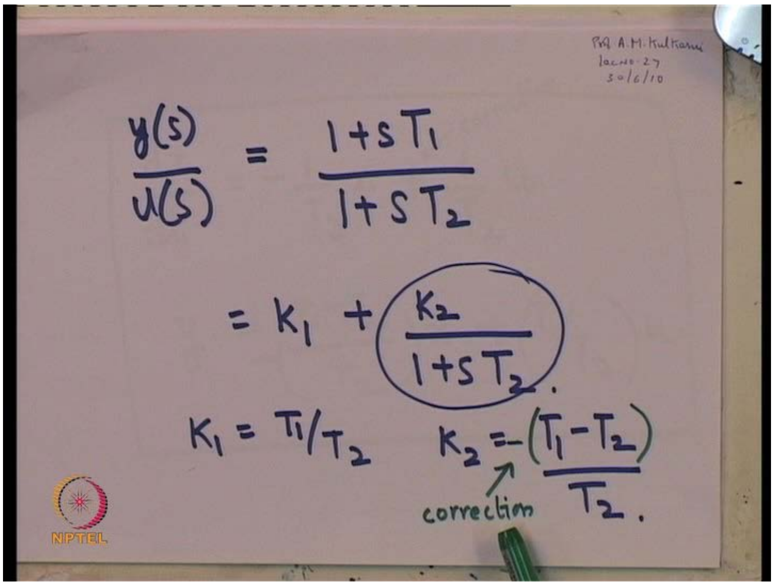

Now, if you look at the how we got this particular block diagram, you will just see that the transfer function y of s by u of s is basically 1 upon 1 plus sT 1 by 1 upon 1 plus sT 2. You can represent this as K 1 plus K 2 upon 1 plus sT 2 and you can easily verify that K 1 is nothing but T 1 by T 2 and K 2 is nothing but T 1 minus T 2 by T 2 this is the first order block, which we have seen already so, that is why we get this transfer function which or rather the lock diagrammatic representation in terms of the integrator as shown in this figure.

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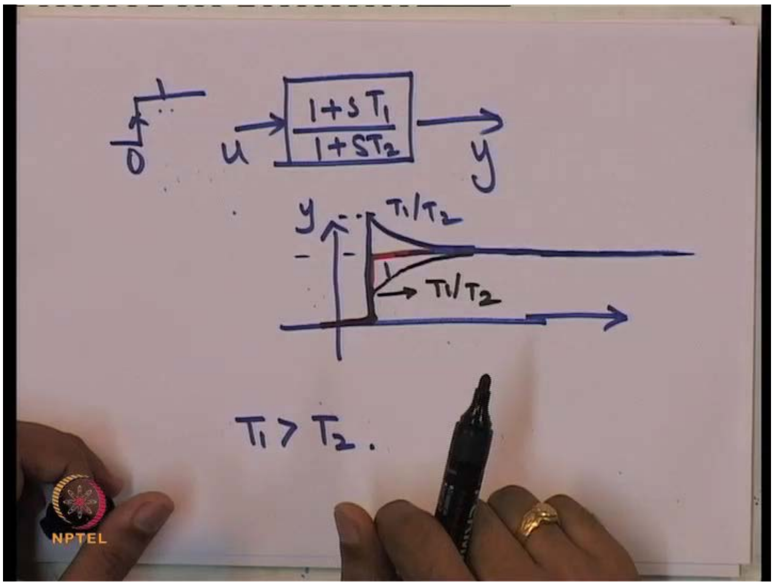

Now, a thing about the steady state response of this to a step change, if you give a step change to this transfer function 1 plus sT 1 upon 1 plus sT 2 what you will get at the output, is depending suppose if T 1 is greater than T 2 what is the steady state gain of this transfer function, well it is very apparent that this transfer function has got a steady state gain of one, you just put s is equal to 0 here you will get what is known as the steady state gain for a step input. So if you have got a step unit step in that case, your steady state value is equal to the output input so, the steady state value will be one so this is the steady state value this time and this is y.

Now, the transient value if T 1 is greater than T 2, you will see that for high frequencies which also define the transient gain, you will find that if you put s is equal to j omega and make j omega tend to infinity you will find that the gain of this is T 1 by T 2 which is greater than 1. So what you can expect is, if you give a gave a step input if I give a step input the output will be like this, so this is one this is T 1 by T 2 on the other hand in case T 1 is less than T 2 your output will be like this is T 1 by T 2.

So in this case, this it is called a lag compensator, why it is a lag compensator? And why it is lag compensator, when T 1 is less than T 2 is something, which you can easily try to find out, by looking at the frequency response of this, I leave it to you. Now, the state space representation of this is quite easy to find out in fact, if you look at the block diagram, which is given on your screen, it is quite easy to derive this; so what comes before the integrator is your state the derivative of the state.

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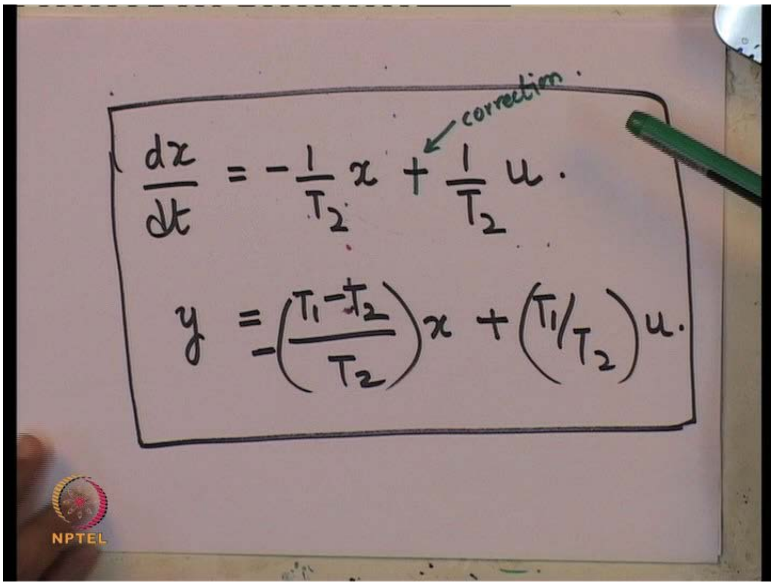

So you can write this as, dx by dt is equal to, minus 1 by T 2 x minus 1 by T 2 into u so, this is actually the state space the differential equation, the output is T 1 minus T 2 by T 2 into x this is minus of it and this is T 1 by 2 into u, so this is what you get as a state space representation so just remember, that for every transfer function representation you can get a state space representation, a state space representation is in some sense more rich, in the sense that it tells you, a you know the underlined differential equation, it also tells you because a looking at the Eigen value we can even tell about tell the time response what the time response is going to be of course, using the transfer function representation itself in the Laplace domain, you can also get the time response depending on the Laplace transform of the input.

But working with the state space, if equations and differential equations is more convenient later on, when we will be doing numerical integration as well as linearized analysis, Eigen analysis of the system. It is better to write everything in the state space form but typically, what you will be given in most of your manuals, and you know work sheets of your synchronous generator excitation system; you will find that it is usually block diagram will be in this form, using transfer function blocks. Now, the reason why I have discussed these three important transfer functions, in fact you have not yet gone come to the main thing that is the regulator transfer function.

Usually, most of our controller including regulators, stabilizer, limiters, will be made out of transfer functions of this kind, the first one is the simple first order transfer function, it is basically a low pass filter kind of characteristic wash out circuits, which allow transients through but do not allow this steady state to go through because it has got low gain for low frequencies, this lead lag block on the other hand is something which you can by choosing the appropriate values of T 1 and T 2 get the frequency response of your choice of course, you have only 2 degrees of freedom that is T 1 and T 2 here. Some of the obvious blocks which you will, I am not discussed explicitly or the gain block you know, you just have a gain, a summer, a multiplier; a multiplier is a non-linear block, so it cannot be really you know you cannot form an integrated transfer function in case you have got multiplier blocks anywhere.

Here, you do not have multiplier blocks in these three transfer functions which I have, the block diagrams which I have shown you here, they have got only summers, gains, and integrators but you could have under certain circumstances limiters and multipliers coming into the block diagram, which make your system non-linear, so the linear part of the system is usually shown with the block diagram, the transfer function block diagram and I hope, you have got now an idea about what kind of differential equations they represent in some special cases, you know how the they behave as well, the three special transfer function which I described to you, the regulator itself will be made out of some of these blocks.

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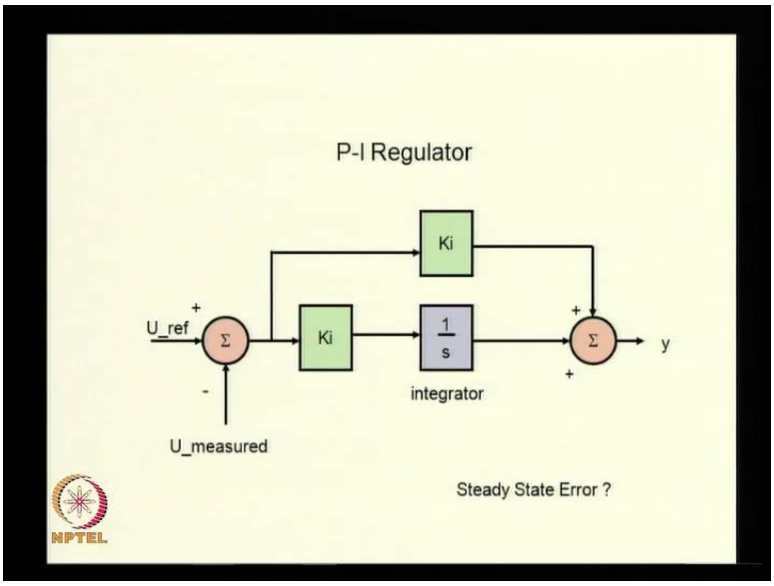

But the typical structure of a plane regulator, it could be containing some of the blocks which I had mentioned sometime back but a plane regulator a plane P I regulator or a proportional integrator regulator has the got this kind of transfer function, or this kind of representation. So, this is a P I regulator block diagram in which this is the simplest possible regulator, in which in fact I would not call this simplest regulator you can have just a proportional regulator as well, the P I regulator here, shown obtains the error between the set point and the measured value, multiplies it with or gives it a gain K p this is by mistaken it is been written here K I. Usually the representation is K p, K p is the proportional gain, you also multiply it by integral gain K I and integrate it, then sum the output of the integrator as well as proportional gain and get your output y.

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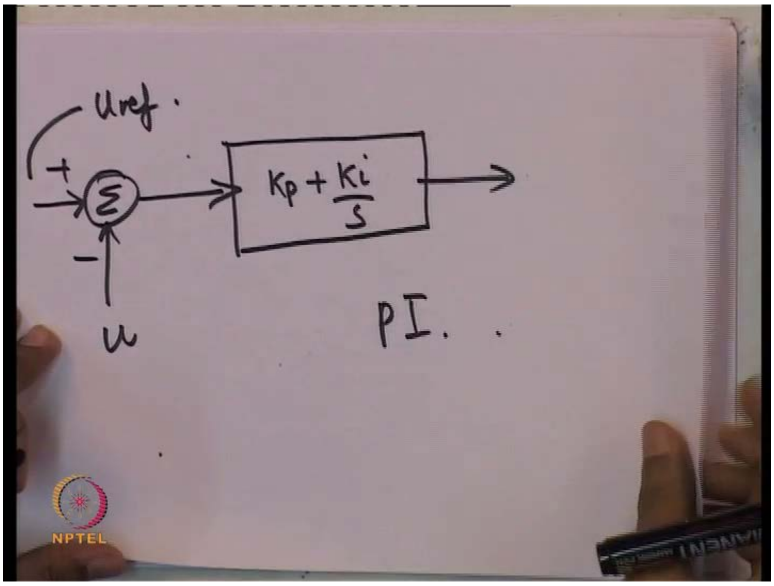

So, the transfer function representation of a P I controller, is the simplest possible P I controller is this, in fact you can have what are known as P I d derivative controllers as well, by adding a derivative block this is u ref.

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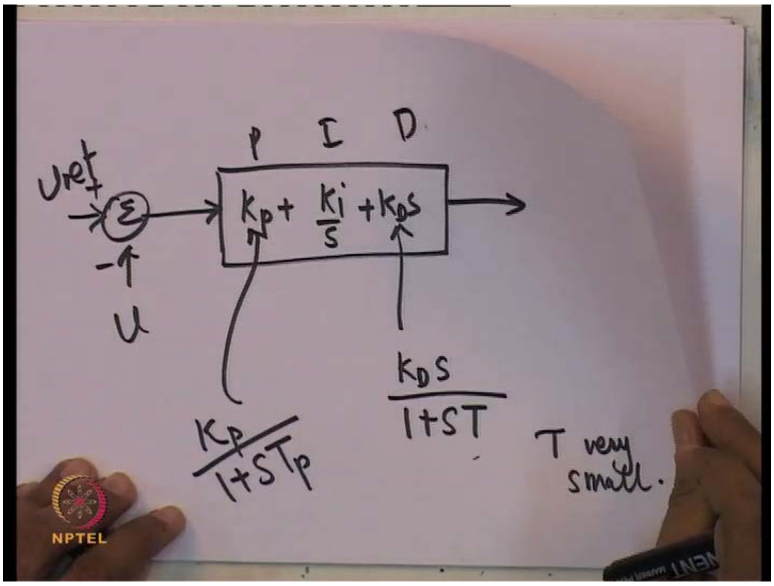

So, this is a p I controller, you can also have a P I D controller which in principle is something like this plus K D into S, This is the derivative, S denotes a derivative. So, this is again the summing junction, which sums the reference value and actual measured value. Of course, if you look at these transfers, these components of your block transfer function block, there is one point which I must make at this point is that, usually it is not possible using a cosel or real physically realizable system, to make a derivative, you can chew on this on what I have just said you cannot physically realize the derivative function using cosel systems.

So, in such a case a derivative is actually an approximate, is approximately realized by using a transfer function of this kind with T very small. So, if you are having transients which are much slower than this T then this behaves almost like a derivative. Similarly, this play a plain gain without any dynamics is often not used usually if you have a plain gain just a gain here. Any noise or distortions in the measured value will get amplified by this gain K so, usually instead of just a proportional gain; you will have a proportional gain with a low pass filter kind of first order transfer function.

So, this is what a P I D controller this is a P I D this is a practical P I D controller. Now I am not really told why this is a regulator transfer function the reason is simply that you take out the difference between the set point and the actual value and you try to amplify it and change the output.

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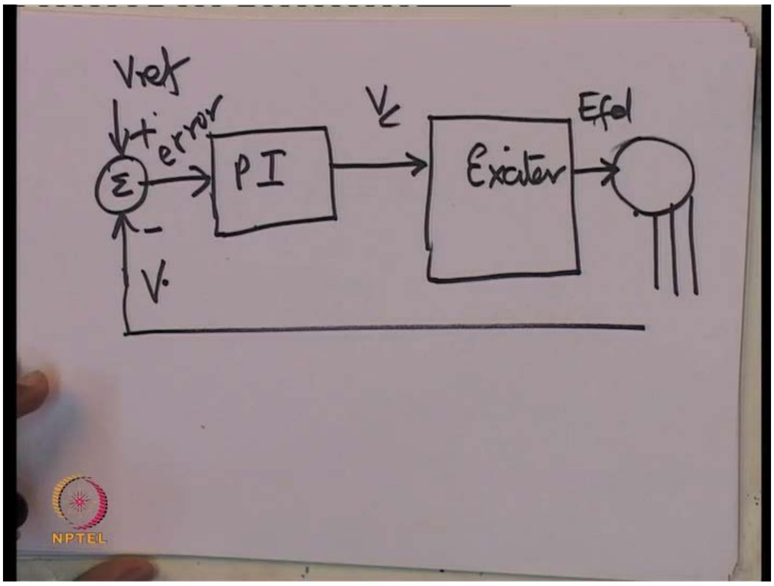

So, why it is a regulator because if you are for example, in a excitation system you have got you are the voltage regulator, the set point is given by u it compares it with the actual voltage. Suppose you have got a P I controller which I have said so, this error is amplified, it is also amplified an integrated in case there is an integral controller and given the output of this, is a control signal, which is fed to the controlled exciter controlled rectifier of a excitation power apparatus, that in turn changes the field voltage of the synchronous machine the synchronous machine field voltage changes the terminal voltage of the machine so, this is E fd and this is controlled signal we call it V c this is how the system works.

So, if you have got an amplifier it tries to change this till this error goes down to 0, now of course there is a catch here, should error here become 0 in steady state if you use a P I controller the answer is yes. Look at the block diagram, which is given in your screen note that you have got an integrator at the bottom here this is an integrator.

Now, if you have got an integrator what is the job of an integrator, well it integrates so, it integrates whatever appears at its input here, which is just after the propositional integral gain. So, the thing is that if you want to reach steady state you should stop integrating, now what is that mean if you are in steady state it means that the all the variables reach a steady value. Now if a integrator has got an input, which is non zero there is no way, you will be in steady state, because the integrator keeps on integrating whatever is there at the input. So, if you are using a P I regulator in that case, the input to the integrator has to become 0 the input to the integrator is nothing but K i into the error that is the U ref minus U measured.

So, it follows that in case, you are in steady state and you are using a p I regulator, then the steady state error is 0 so you can say that if your system is working well it is stable that is of course, not something which I have proved, the point is that if you are designed your system, your feedback control system well it is stable, then in steady state if you are using a P I controller and a controller, which has integral component as shown there in that case a steady state error is driven to 0 is that so just to do a quick example.

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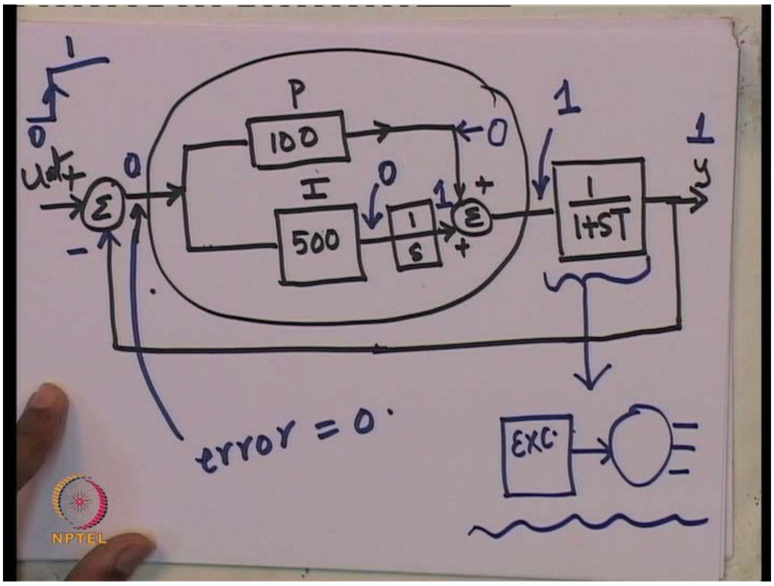

Suppose I have got a P I controller, say this is got a gain of 100 this is a proportional controller this is a integral controller, suppose this gain is 500 and this is added here, you have got an integrator here of the P I controller so, this is a I channel the P channel this is your input this is U this is U ref this is U measured, suppose the system which you are trying to, this is just an arbitrary system.

Suppose I have got a system of this kind, this is the P I controller which is trying to get the output y equal to U ref so, this y has to become equal, we want it to become equal to U ref so, if you have got a system like this you will find that in steady state, this error which appears here this is the error has been driven to 0 in steady state. So, in fact if U ref is a step input from 0 to 1 in steady state this error has to be 0.

So this will be 0, if this has to be 0 and this is a feedback system of this kind y also has to be 1, if y has to be 1 can you tell me what is the steady state value out here? Well it is going to be one, remember that the steady state gain of the transfer function 1 upon 1 plus sT is 1 so if this is one what is the value here see this is 0 the error is 0 if you just multiply anything with 0 of course, it is going to be 0 here. And this is one.

So, the output of the integrator is one, the output of the integrator is one, does it mean that the input has to have a certain value. Well no this is the value which the integrator has integrated up to the input to the integrator in steady state has to be 0 otherwise, the integrator will integrate whatever input comes and changes this value. So, this is the steady state values in case you have a step change given to this system of this kind which has got a P I regulator and the thing to be controlled has a under transfer function 1 upon 1 plus sT, in our case you will have to replace this 1 upon 1 plus sT by the dynamical system corresponding to the excitation power apparatus and synchronous generator, the y is nothing but the terminal voltage.

So, this plant is very simple in our system the plant which we are trying to control will consist of the excitation system apparatus as well as the synchronous generator. So this is just a toy example, in actual practice for our systems you will have a complicated plant, which has to be controlled so, a regulator is you can say trying to control a plant.

Now so a regulator, if you look at it consists typically of a proportional controller or a proportional integral controller or a proportional integral derivative controller, if you have got a proportional controller for example, something simple like this simply a gain and here is the output, this is a proportional controller.

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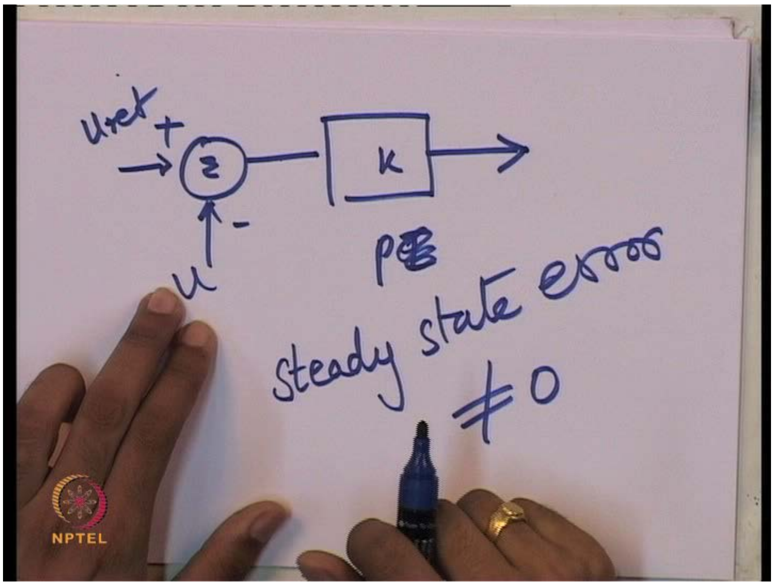

So this is u ref and u, remember a regulator is defined something which is trying to get a measured value equal to the set point value so, this is all the regulator now this is the proportional controller, now the proportional controller to have any non zero output. It has to have a non zero input so it follows that if you are using a proportional controller in that case, steady state error between the set point and the thing you want to follow the set point is not 0, not equal to 0.

Why? Because in case you want to have this to have any control signal which is going to affect your excitation apparatus, then this has to be non zero. Now if this gain is very large, then to get a certain control signal in order to obtain the voltage you desire or near the voltage you desire, in that case the error need not be too large.

So, if I use a larger gain in a proportional controller, then the steady state error is going to be lower because to get the same value of the excitation required to get a certain value of u, you require a smaller value of error. So, in a proportional controller steady state error is not equal to 0, but a high gain proportional controller will have lower corresponding steady state error, now as in any control system design it is not guarantee that you system is going to be stable for any kind of gain so, you actually have to do a control system design in order to ensure that your system is stable under various situations.

In fact we have, I am sure you have done a course on control system design sometime. In the previous years, now this particular system which I had showed you which is shown here on the sheet, is in fact, you can show that this is going to be stable if t is greater than 0 then you can show that this particular system is stable or you need to any feedback system is stable for any value of P and I.

So, we can have a system of this kind which is stable, you can just verify this that at least if I have got just a proportional controller it is easy to show that the system is always stable so, this is something you can just check out is proportional is it stable with just a proportional controller, is it stable with proportional integral controller and what are the gains for which it is going to be stable in terms of this cap this time constant t so, this is a separate you know subject of control system design, which is related by power system dynamics, if you are going to do power system dynamics you should know a bit of a little bit at least about control systems design and stability.

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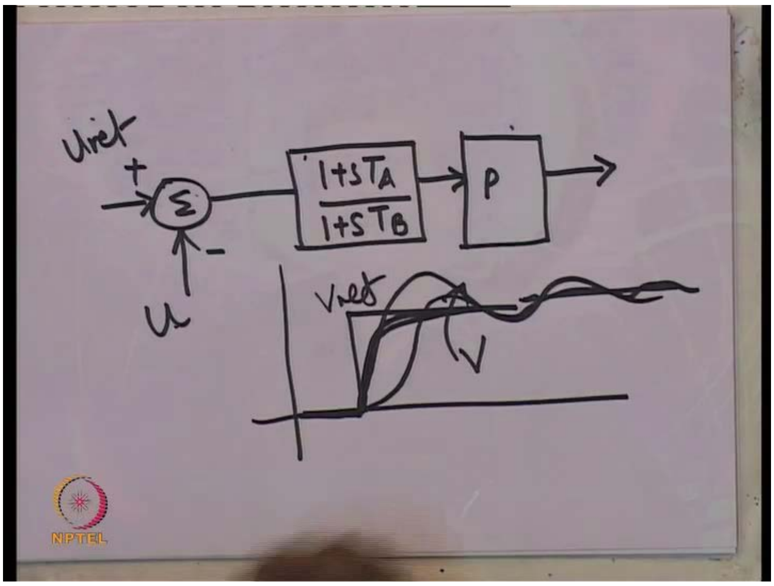

Remember that just using a proportional controller or proportional integral controller is sometimes not adequate, that in that context you may actually have to use the transfer function, which I have discussed before for example, instead of a plane proportional integral controller you may you may not get a stable performance so, you may have to add a lead block or a lag block in order to improve the performance of the P or P I controller, which you will use.

So, this is the one thing, which you may see in a you know in a control system, that in addition to the proportional or proportional integral controller, you also have these blocks which try to improve the response, what do I mean by improved response? Well one of the things you should ensure with your regulator is that if for example, I give a step change this is one way you specify the performance of a regulator if I give a step change, how much time does u require to settle down so, u is actually determined by fairly complex processes, remember that for AVR this will the output of this is the control signal to the excitation apparatus, the excitation apparatus itself may have very significant dynamics as we see in a brushless excitation system then that determines the field voltage.

The field voltage again changes results in the terminal voltage change of a synchronous generator it is a fairly complicated way. Because you will have to actually solve all the differential equations either numerically or if you feel linearize it around an operating point you can even do a linearized kind of analysis, what I want to say is that eventually the u in a automatic voltage regulator is going to be determined by a fairly complicated set of dynamical processes.

So, eventually a response is going to be something like this it could be something like this so, for a step change if you look at this for a step change in the input you could have for example, so this is your voltage reference the actual v could be like this now obviously you should design your system so that it settles fast. If a system settles down fast it also means that the modes which are observable in the voltage are more stable, they are more having real parts which are having more on the left hand side of the complex plane, and as a result of which they decay very fast.

You also would like your rise time to be fast, you do not want it to rise like this the best possible response could be something like this; you wanted to rise and settle down immediately.

So that kind of response you could want, in case of a excitation system remember that the conditions of the synchronous generator whether it is open circuited or no load or it is at half load or a full load will really change the kind of response you will get, the plant of the system this is the excitation excite a power apparatus as well as the synchronous generator and power system to which it is connected will really determine the response.

So you what you need to do when you are trying to designing a system is to use not proportional only integral controller but you may require to use a lead or a lag block in series with the proportional controller, in order to get some degrees of freedom, the degrees of freedom are in fact he time constant T A and T B of the lead or lag compensator, you get these degrees of freedom in order to improve the response so this is what is very important which you should know.

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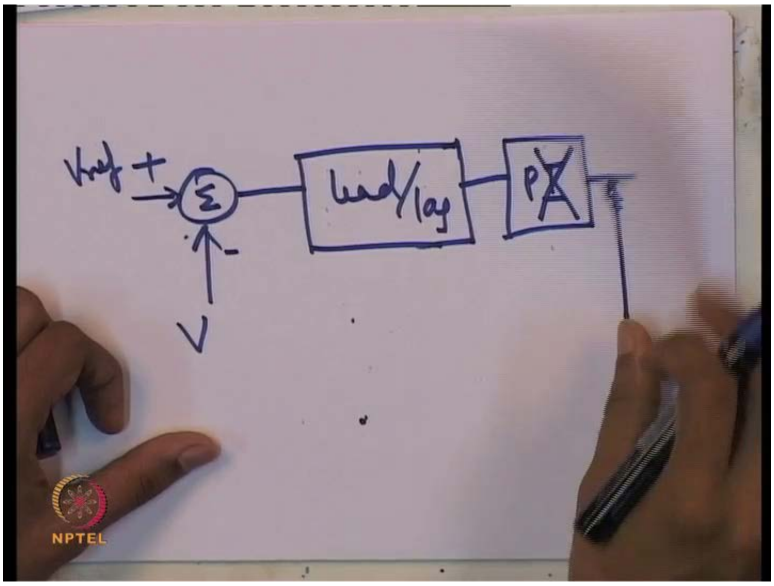

So, if you look at a typical regulator, it is not just consisting of proportional controllers typically you will find that it is consisting of V ref V, a lead or lag block usually you know depending on the situation you could use most likely you will use a lag block if you want to achieve some functionalities and a P I controller in often you will find is just a high gain proportional controller integral component is absent in many kinds of AVR.

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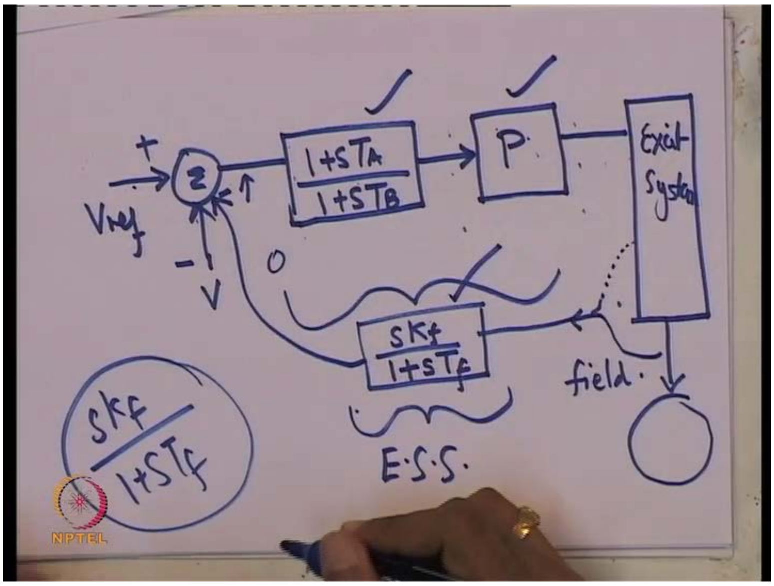

So, this is often called an excitation system stabilizer, remember it has got a transfer function which is s K f upon 1 plus s T f, so this is essentially like a wash out block with a slightly difference in gain of course, the steady state gain would be K f. So this sorry this the transient gain would be K f and the steady state gain is 0, now one of the thing we should remember though this excitation system stabilizing is being fed into this summing junction its output in steady state is going to be 0, so it will not interfered with the regulation function out here, So, in steady state this will be 0 so we will try to be driven to be V ref by this controller, so this does not contribute anything at the summing junction if something gets something non 0 is contributed at the summing junction then the regulation function will get compromised.

But, this is not the case because in steady state the output of this is 0 so you may find, we will not actually go into the design of the AVR itself but you may find blocks like this in addition to the regulator the basic regulator which is a proportional controller. So, this is what our controllers typically look like. There is another block, which I need to discuss at this point, we have already a kind of got a flavor of that block before that is a limiter.

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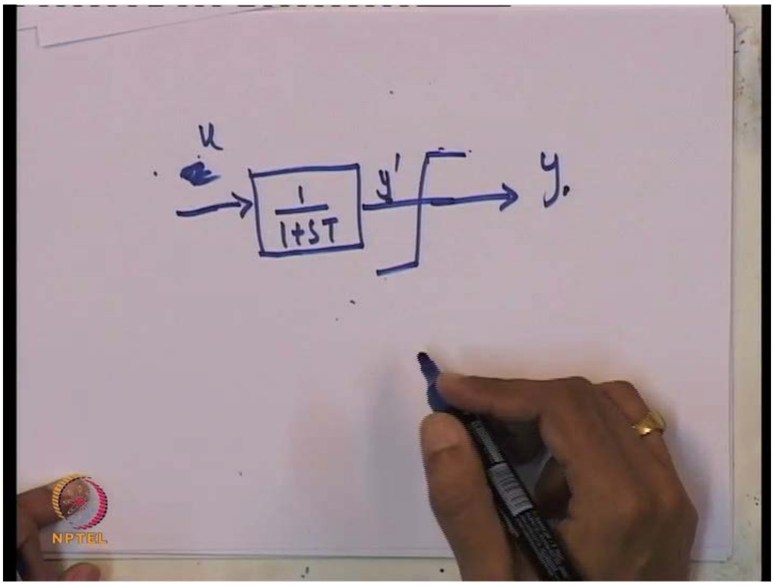

Now, we have without much spending too much time, if u recall this was the a kind of you know, symbolic representation of a limiter which was given so if you have got an input u you get a clipped to the values specified here so if I specify this value as plus 1 and minus 1 in that case this input, suppose you have got output y dash, y will not be equal to y dash if y dash exceeds these limits it will get clipped at that limit, this is often called what is known as a soft limiter, in fact we have used the limiter to model the converter, static converter which is used in the excitation power apparatus.

Now, this is only a simple clipper it simply clips the output. So, if you find if you have got something like this is simply clipping the output, which appears here but remember it does not affect, the output y dash, so it allows y dash to get any value you want but it clips the value of y dash in order to get y so this is a soft limiter you can have another class of limiter which is called hard limiter in order to do that let us take the example of a simple integrator.

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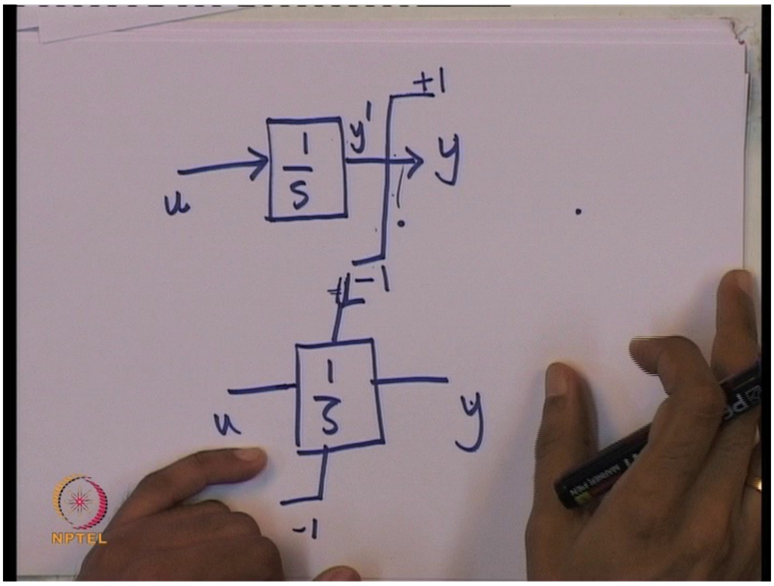

Suppose, I have got an integrator and I try to limit it, this is a soft limit so if you have got an input u it will get integrated in order to get y dash y will be the clipped value of y dash of course, y dash will not exceed any of the limits specified here; for example plus one or minus one this is an example of a limit in that case y dash is equal to y so only, when the limit is exceeded that these limiters come into play. A limiter makes a system non-linear so although our transfer function representations excreta are actually of linear time invariant systems, when you have limiters included in the transfer function blocks effectively our system becomes non-linear.

So, let us now look at another kind of limiters it is represented in this fashion, the difference between these two limiters, this limiter and this limiter is that, in case the output y exceeds the limit or tends to exceed the limits the integrator stops integrating, so just try to chew on this statement the integrator stops integrating in case the limits are exceeded, here the integrator does not stop integrate it keeps integrating the output simply gets clipped.

So, y dash and y need not be equal and the output gets clipped, here if y dash exceeds the limits specified here say plus 1 and minus 1 say this could be anything in that case, the integrator simply stops limiting in some sense you can say that it starts integrating 0 instead of u, it starts integrating again when there is a chance that the limit the output y can come out of the limits.

So for example, if the output is at plus one which is the limit specified here then this integrator stops integrating till u starts becoming negative and there is a chance for the y to come out or start coming out of the limit, you can take say an example of a simple system like this.

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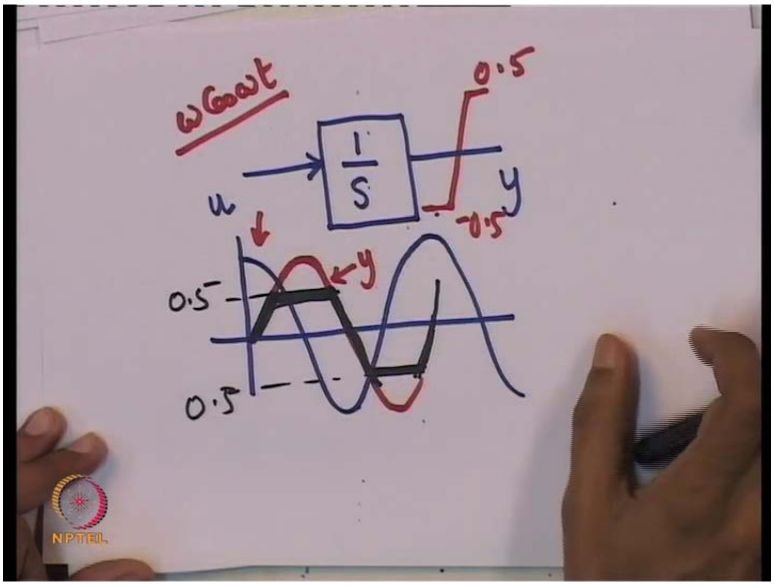

So, you have got an integrator and I am going to integrate the input u say u is cos omega t. So, let us assume that this integration has been going on for a while, I will just show it this way, suppose u is cos omega t then of course, the output y would be, so if you have got input as omega into cos omega t and you try to integrate it and you will get sine omega t, so omega into cos omega t suppose is this, will eventually get sine omega t is something like this yeah, so this is your sine omega t this is your output y, now suppose I have got a soft limit which is put at plus 0.5 and minus 0.5 in that case the output would be clipped so, what you will get in fact at y is not this something which is clipped at 0.5 plus 0.5 and minus 0.5

So, this is the response of a soft limiter so it just clips the output, so what you will at output is what is in black that is this, I will darkened it a bit, so that you can see it, what we see is the integrator does integrate as per its rule, so the red curve is what you get simply by integrating omega cos omega t. But what you get at the output is the clipped version of this the integration operation itself is not affected.

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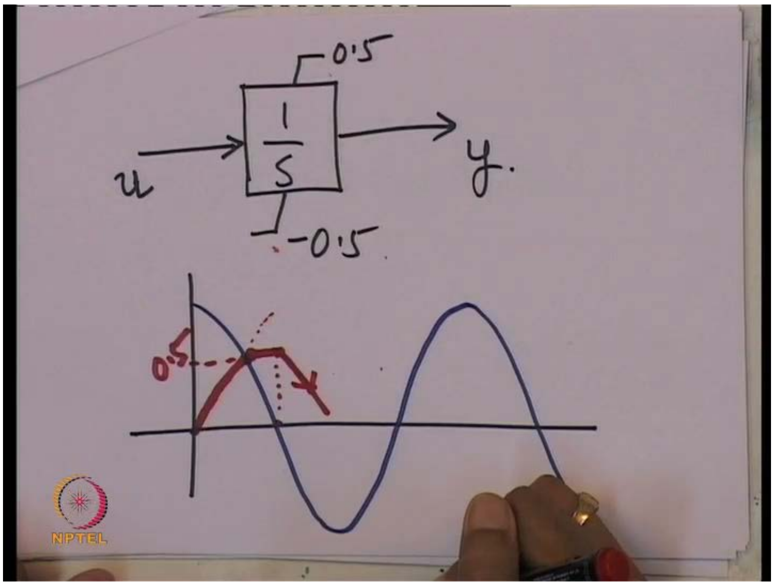

Now, if you on the other hand try to integrate via using in the presence of a hard limiter. So, you have not very much well drawn but anyway so this is cos, if you look at how this particular system behaves you will see that it integrates up to 0.5, this will not actually will not meet at 0.5 but anyway will integrate up to 0.5 after that it gets limited now it will go on staying at the limit. So, what happens is it that the integrator itself stops integrating, it is not that integration is going on at this point we do not continue with the integration we stop the integration and the output remains at this value this is exactly as we got before but.

Whenever the integrant this is u the input becomes negative, there is a chance of coming out of the limit because if you integrate a negative quantity then you start decreasing from where you are, so what will happen is you will come out of the limit right away, so this is this is what happens in case of a hard limit in fact, if you have got a soft limit its this and hard limit it is this, so whenever you have got an integrator which is hard limited you will find that it stops integrating as soon as the hard limit is hit in fact this is desirable under certain circumstances, in this earlier circumstances with a soft limit what happens is the integrator goes on integrating and you may really go on, although your output is being clipped the integration here is continuing and you may find, it is taking much longer time to come out of its limit, even though the input u has got become negative in this case.

So, the input you has become negative at this point but it comes out of the limit only at his point whereas, here with the hard limiter at this instance itself the integration resumes because there is a tendency to reduce the value, because u has become negative, so this is what is known as a limiter, so you will find in it most control systems will be designed with limiters in order to prevent, see what happens if you know your limit has been reached, you do not want to go on making the controller trying to do something anyway it is not getting implemented. So, it is a good idea to put limiters wherever feasible and wherever it is reasonable to do so.

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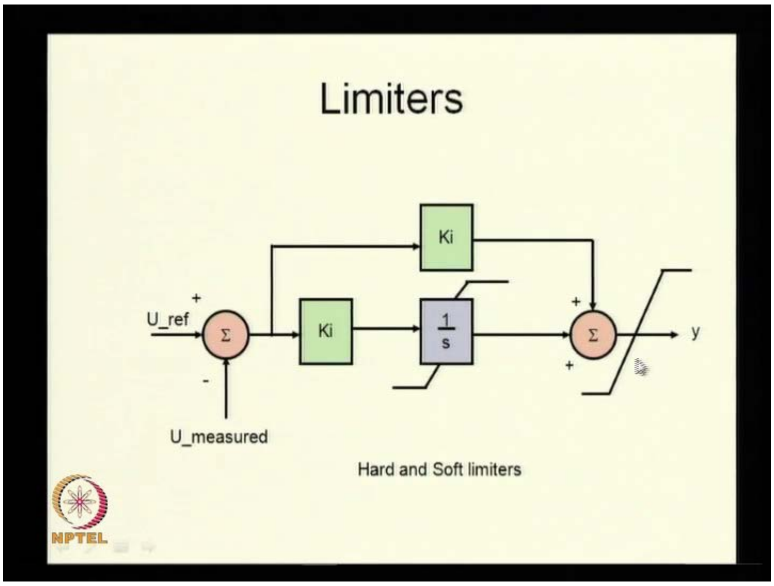

So, you will find typically you have a limiter here on the hard limiter on the integrator and soft limiter here will clip the output as well of course, if you are just in integral controller which is a hard limited you do not have to put a soft limiter again. But here since you have got combination of p and I you can have a hard limiter as well as a soft limiter. So, on the whole you will prevent the values from going out of range. So, this is what typically you will find in your AVR controllers. Now suppose, we want to take up now a simulation of automatic voltage regulator, we have actually discussed the way control systems are typical control systems associated with the regulator R, we have of course, not discussed limiters etcetera right now we will focus on the regulator itself regulating function itself remember that V ref of the synchronous of this AVR can be modified by the limiters and stabilizing functions, whenever there is a need to do.

So, for example, if the synchronous machine field current is exceeded you may wish to sacrifice the regulation function but reduce the field voltage so as to reduce the field current, some equipment limit is being hit then the limiter may wish to reduce the field voltage instead of carrying on with the regulation of function; so in some sense the V ref objective the objective of being making V as close as V ref as possible, is compromised and you would rather maintain limits. We saw that if you want to improve the dynamics of one or more modes of the system, you may actually put in stabilizing function one of the functions we saw was an excitation system stabilizer, but the main characteristic of a stabilizer is that its output in steady state is 0.

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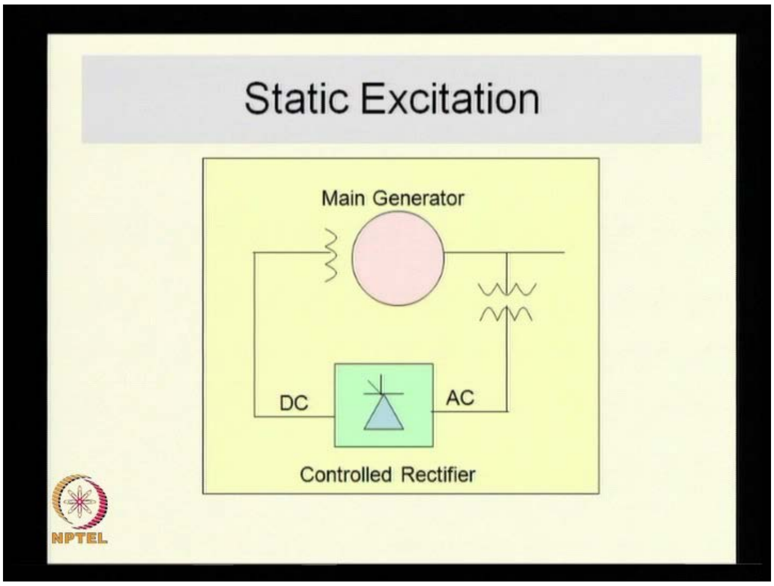

Now, we will move on to try to simulate an automatic voltage regulation system along with a AVR. So, if you really look at what is involved you have got the mathematical functions of the state space representation, which describe how an AVR works.

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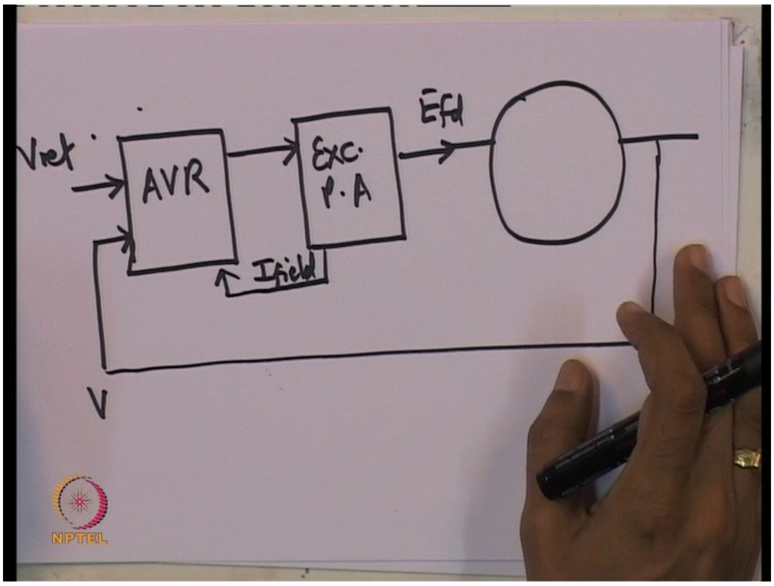

So AVR of course, will require you to have a set point which is given, it takes the feedback of voltage, the terminal voltage of a generator the excitation system gives the control signal to the excitation power apparatus, that gives the field voltage to the synchronous machine, the synchronous machine output is of course, what you measure using a potential transformer which is straight to the AVR, remember the AVR is not a power apparatus this is not a control system.

The AVR itself may take feedback signals like the field current. So, this is a typical structure of the system. What we will do in this the next class is try to analyze a system of this kind so what we will, the simplest thing we can do is, suppose we take a static excitation system.

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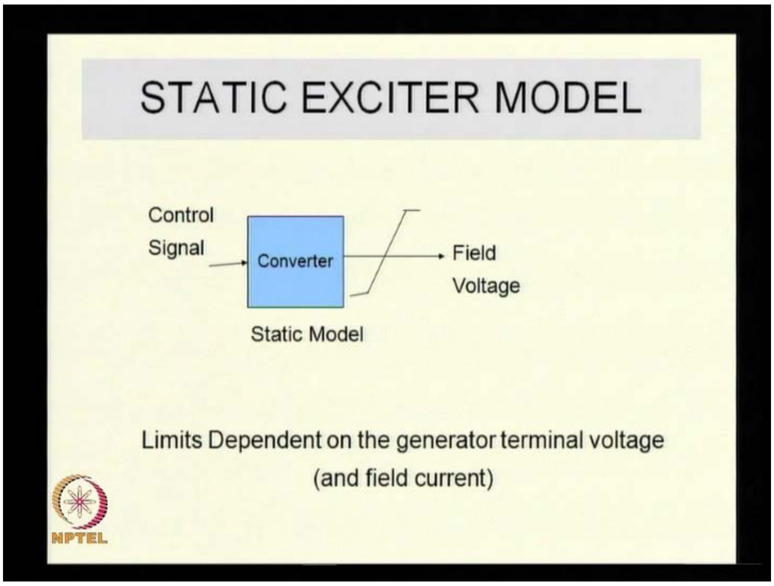

So if you have got a static exciter as shown in the on the on the screen, then the converter model is usually a static one. And only thing which you need to represent is the field voltage limits, the limits of the converter itself I am sorry, the field, the limits of the converter are determined by the terminal voltage of the generator itself because the power apparatus of the excitation system is fed from the terminal voltage of the synchronous machine itself so, if you look at this its fed from the terminal voltage of the synchronous machine so, the limits are effectively decided by the terminal voltage of the synchronous machine.

So, the converter itself will assume that it is a static model it is a simple model in the sense that it implements whatever the control system tells it to do subject to the limits.

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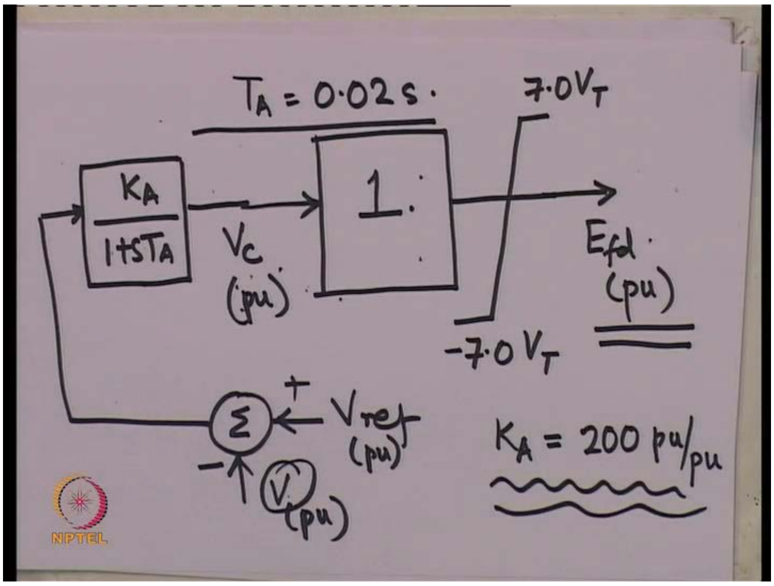

So if I want, so will kind of have, let us say we will just model it this way this is the terminal voltage of the synchronous machine, these are the limits imposed on the converter output by the terminal voltage of the synchronous machine, this is the field voltage.

Let us assume that the field voltage is in per unit, we have defined the per unit system before E fd is one if it results in open circuit line to line voltage for the star connected synchronous generator at a rated speed so, it develops a rated voltage the rated speed then we call that voltage as one per unit.

So we will not represent it in volts but in per units now the control signal which gives this E fd, again can be expressed in terms of voltage it is a signal which is given to this converter but if I say that one per unit of lets define our normalized control signal in such a way that one per unit here or control signal of one per unit results in one per unit E fd, then the gain of the converter becomes one so, this is also is represented in per unit.

The AVR, this is the excitation apparatus the AVR let us assume is a simple proportional controller of this kind, this is the error signal, this is V ref, this is V, so this is what is your AVR and power excitation system block diagram, K A is typically you know it could be say around 200 to 300 or even 400 per unit by per, unit the gains are in per unit. So, what I will do is, I will also do this sum so all these gains are excreta expressed all in per unit so, I have already described what this per unit system means, as far as the field voltage, the control signal, the terminal voltage is expressed in per unit on the generator terminal voltage base there is the rated K V of the synchronous machine so, if I represent it this way then k a is typically of this value, it would be say 200 300 or 400 it is usually kept high, so that to get a value of say E fd one here the amount of steady state error required here is very small, remember that the now T A is usually very small this is of the order of one cycle that is all say twenty milliseconds so, this is the block diagram of the excitation system with just the regulator included we could have included many more possibilities in fact in this course in the course we will not do that.

We will included a simple excitation system model, using a static exciter and this we use to study the voltage regulation of a synchronous machine, what I will do is now incorporate these equations which are you know embodied in this transfer function or this limiter and summer blocks write them a state space equations, interface them with the synchronous generator equations connect the synchronous machine to another voltage source and try to regulate the terminal voltage of the synchronous machine.

We will do one extra thing, we will not connect the synchronous machine directly to a voltage source we will connected it via a model of a transmission line a very simple model of a transmission line, modeling of a transmission line is something we will do in brief later in this course we will just take a simple model when we are studying this. So, with this we will come to the end of this lecture. In the next lecture, stay on for the incorporation of an AVR into the synchronous machine equations and the simulation of the voltage regulation action.