Power System Dynamics, Control and Monitoring
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Lecture - 50
Reactive power and voltage control

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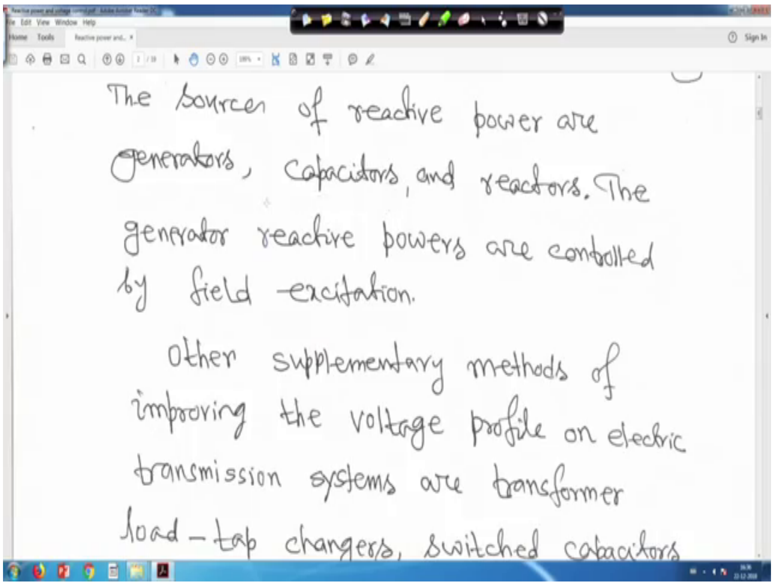

So, that is told you that reactive powers are in a previous lecture right that your reactive source of reactive power sources of reactive powers are synchronize generator, capacitors and reactors, right.

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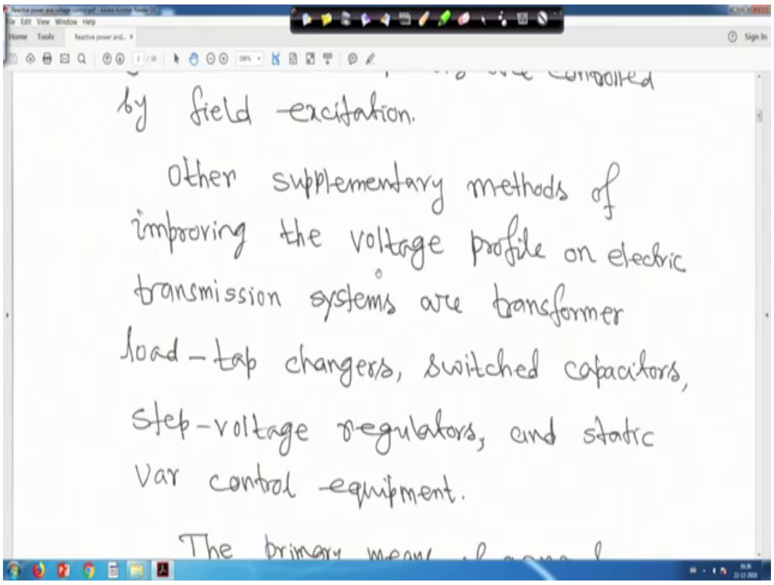

So, other supplementary methods of improving the voltage profile on electric transmission systems are transformer load-tap changers, you know that switched capacitors, step voltage regulators and static var control equipment, right. So, that means fax devices.

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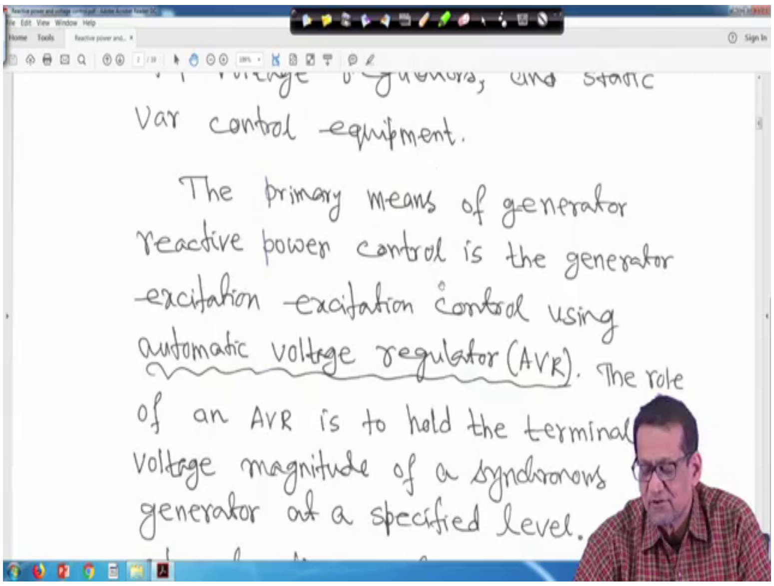

So, the primary means of generator reactive power control is the generator excitation. These excitation is retained twice, right sorry just hold on. So, this this excitation is actually written twice.

It is here only, right. So, excitation control using automatic voltage regulator that in short we call AVR little bit of AVR transfer function that we have seen in your what you call in synchronous machine modelling, right. So, the role of an AVR is to hold the terminal voltage magnitude of a synchronous generator at a specified level, right. So, the schematic diagram of a simplified AVR is shown in figure 1, this figure right.

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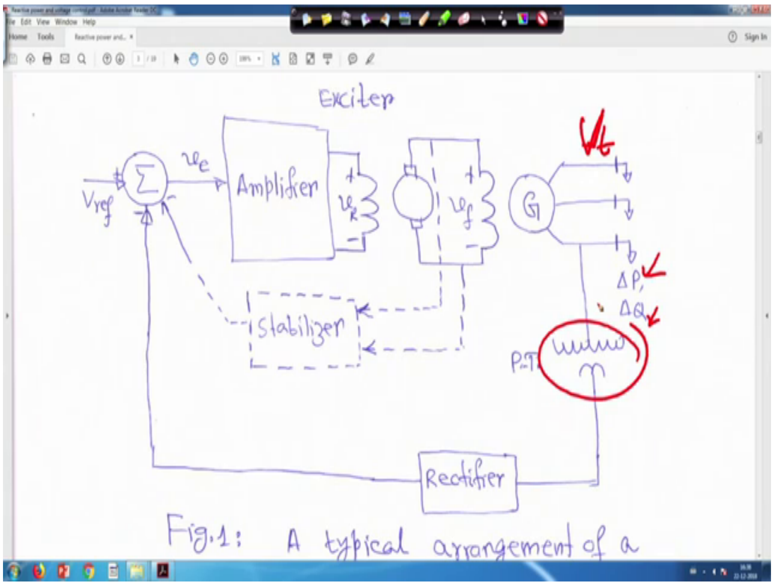

So, this is actually the amplifier, a gain is there. So, this is the voltage V R and this is the excitation system and a schematic diagram and this is the synchronous generator.

These three phase three terminals are there, this side is dual power delta P, delta Q and this is potential transformer, then one rectifier is there. It will be rectified and your what you call and given feedback. That means, any reference signal will be there, voltage reference signal and it will be compared and one stabilizer is there, that will see the dash line I have shown from here, it is excited by their what you call by the exciter voltage, right. So, the stabilizer actually it is stabilizing transformer, right and this transfer function directly will as shown because time is short right, but generally transfer function it is a derivative type of thing that is your F feedback.

That is some s k divided by 1 plus s t something like this, right. So, this is a schematic diagram and terminal voltage here it is V t right, it is I forgot to wrote it the terminal voltage is V t right and this is the change in your power delta P and delta Q and this is a potential transformer. So, this is a typical schematic arrangement for your what you call of a just hold one that yours automatic voltage is a V R. So, this dash line we will consider later right. This this stabilizing transformer actually we call stabilizer we will consider later.

First we will consider this one.

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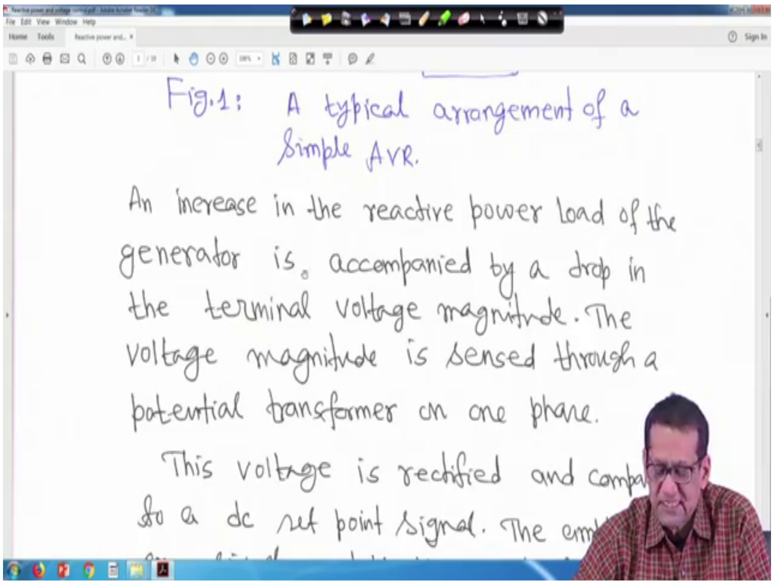

So, an increase in the reactive power load of the generator is accompanied by a drop in the terminal voltage magnitude this I told you right. So, the voltage magnitude is sensed through a potential transformer on one phase, right. So, this is actually potential transformer is here right.

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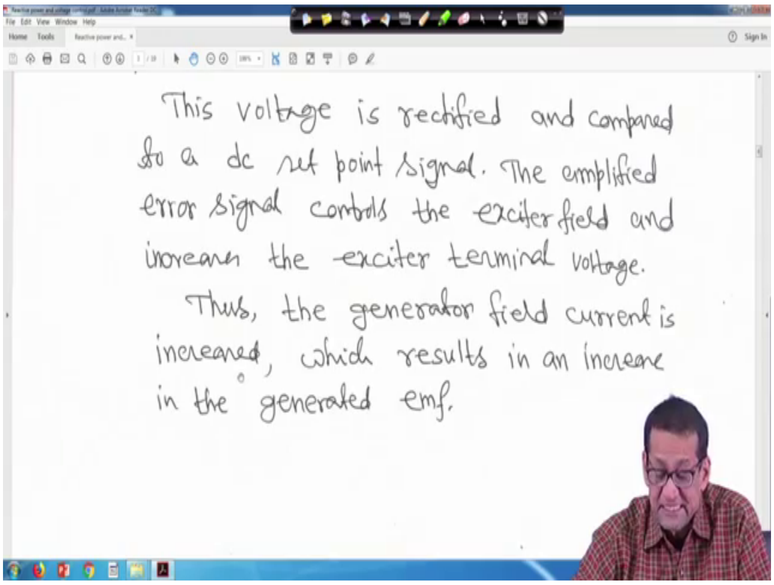

This voltage is rectified and compared to a dc set point signal right because that is why rectifier is there. The amplified error signal controls the exciter field and increases the exciter terminal voltage, right. Thus the generator field current is increased which result in an increase in the generated emf this is little bit you have studied in your machine synchronous machine topic, right in machines.

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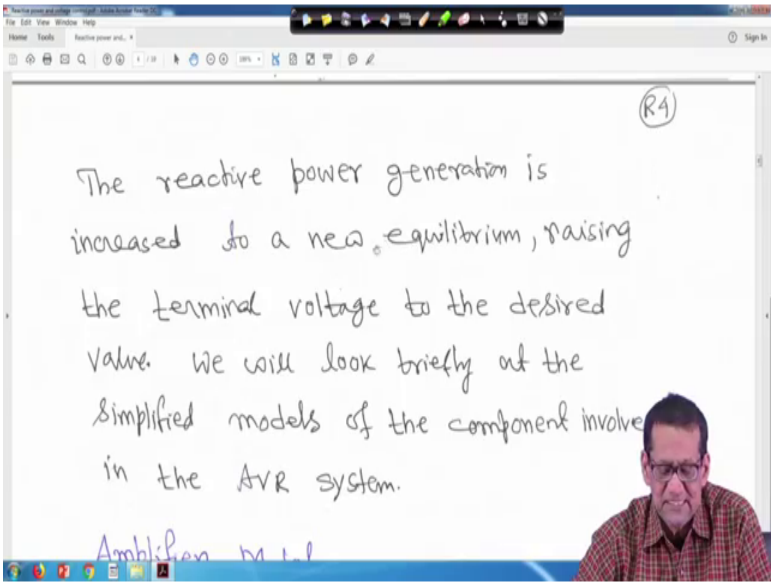

So, the reactive power generation is increased to a new equilibrium raising the terminal voltage to the desired value right. We will look briefly at the simplified models of the component involved in the V r system.

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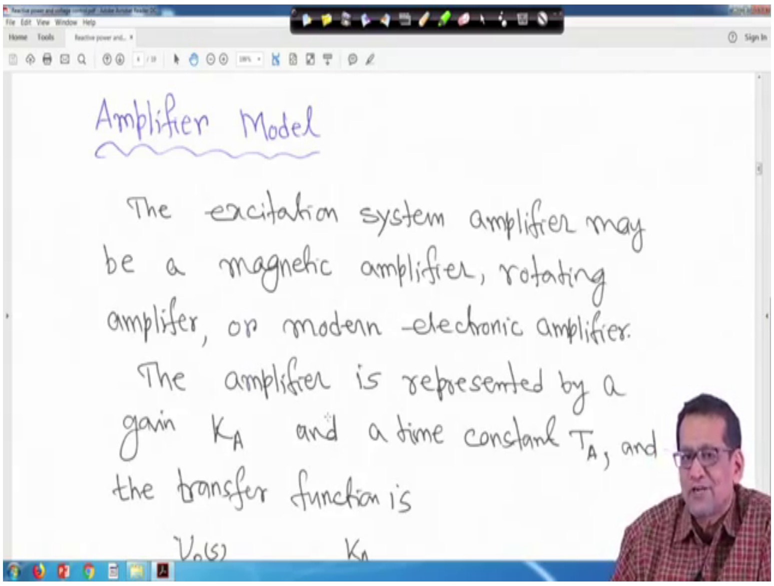

So, basically our objective is that little bit of control modelling. So, the first we will see the amplifier model, the excitation system amplifier maybe a magnetic amplifier, rotating amplifier or modern electronic amplifier. The last one is preferable the amplifier is represented by gain K and the time constant T A and the transfer function is actually V RS upon V ES is equal to K A upon 1 plus S T. S TA that means this one.

If you go to the schematic diagram that is V RS upon this one, V ES is equal to K A upon 1 plus S TA. V E is the error right V reference minus your this signal if we make this signal I rectifier signal.

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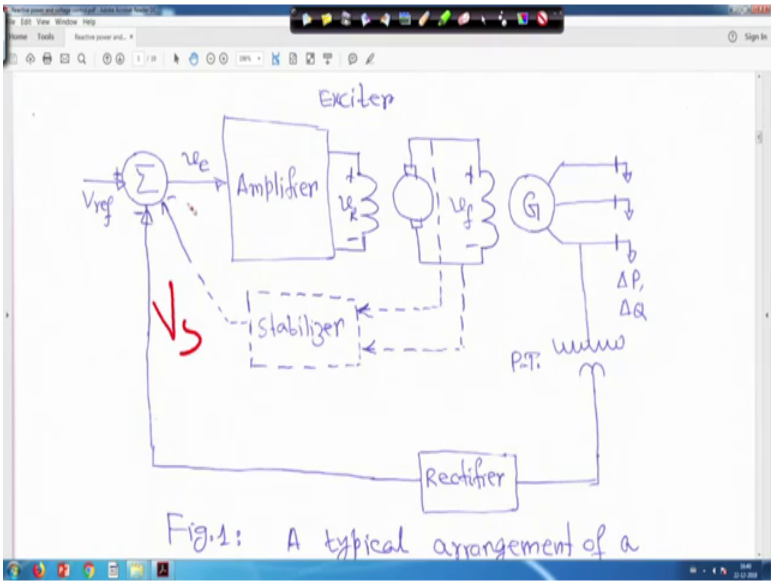

So, it is V S. So, V E is nothing, but the error signal V reference minus V S right. So, that way we represent by your what you call a first order transfer function, right. So, it is K upon 1 plus S TA. So, typical values of K the amplifier gain are in the range of 10 to 400. The amplifier time constant is very small actually in the range of 0.02 to 0.1 second and often is neglected. Sometimes we neglect this and simply we consider that it is a gain, right.

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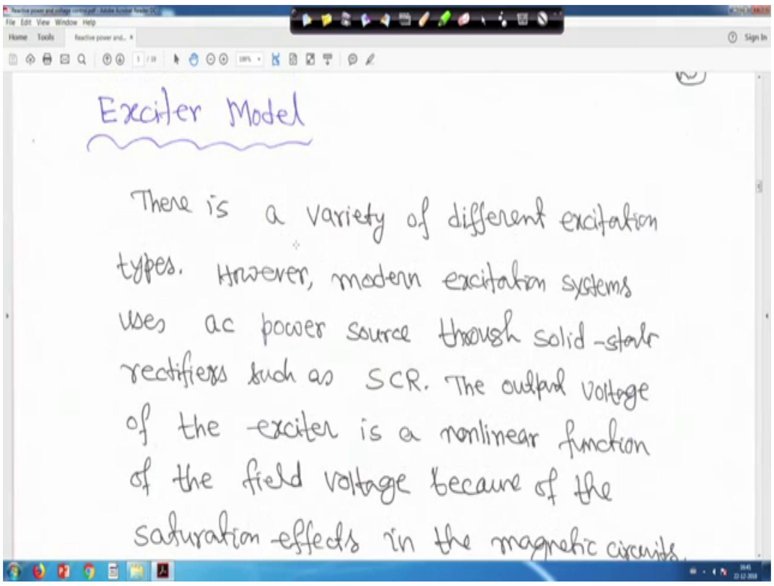

So, K next is exciter model. So, actually this exciter modelling we will simplify it, but just see how. What I have written here there is a variety of different excitation types if you look into that. If you see the literature, you will find that IEEE different excitation systems and given right recommended, however modern excitation system uses ac power source through solid state rectifier such as S CR. The output voltage of the exciter is a non-linear function of the field voltage because of the saturation effects in the magnetic circuit.

This you also know right that is why when I use covering synchronous machine I did in consider the non-linearities of saturation effect, then it will take long time to discuss those things right. I have only considered their linear part.

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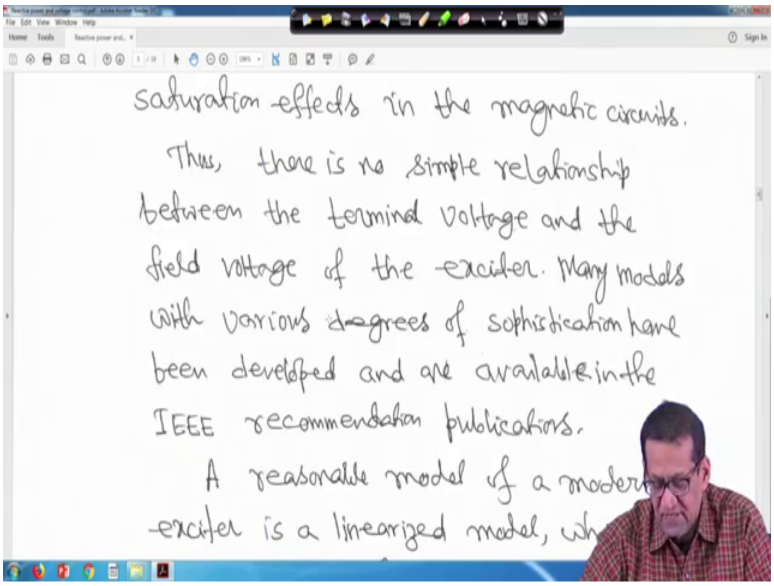

So, thus there is no simple relationship between the terminal voltage and the field voltage of the exciter. Many models with various degrees of sophistication have been developed and they are available in the IEEE recommendation publications, right.

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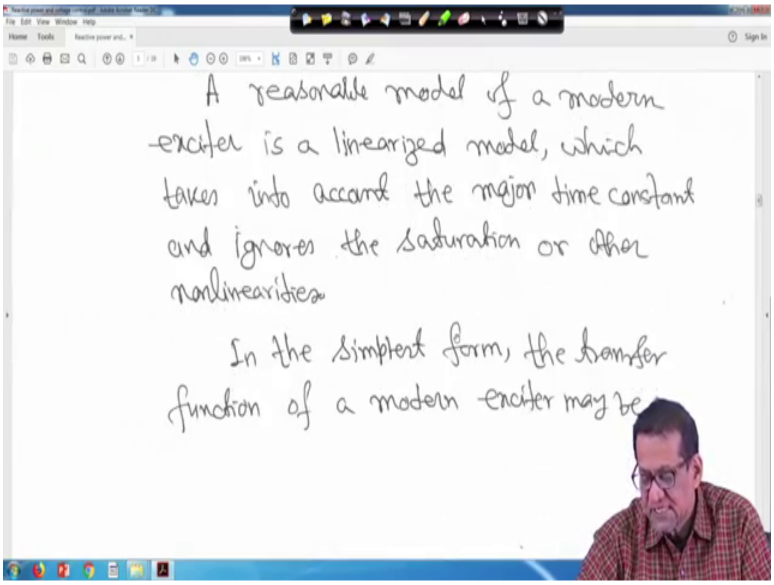

A reasonable model of a modern exciter is a linearized model right which takes into account the major time constant and ignores the saturations or other non-linearities.

So, in the simplest form the transfer function of a modern exciter it may be given as represented by a single time constant T E and a gain K E.

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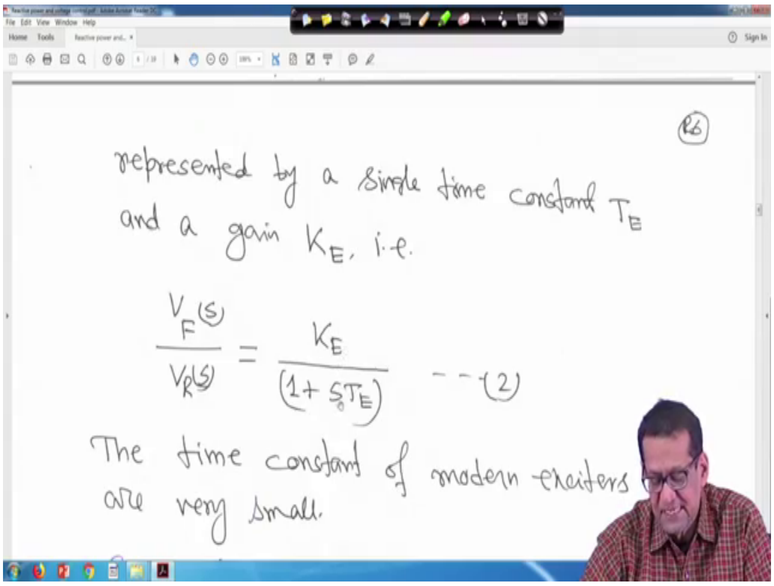

So, V F S upon V R S, it can be written as K E upon 1 plus S T E, right. That means, you are if we go to the schematic diagram, once again here once again that is your this is actually V F, this is V F S, this one I am making here small. There its capital meaning is same.

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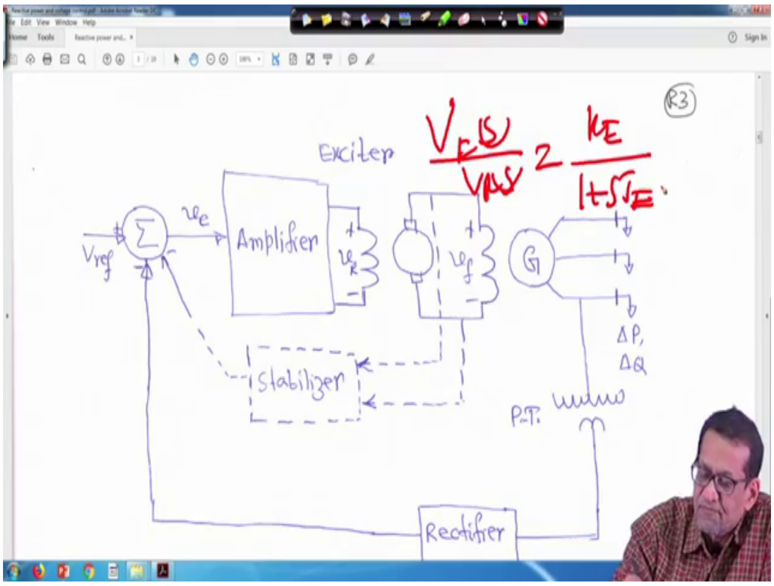

So, V f that is your V F S upon V R S is equal to your exciters at K E upon 1 plus S T E. This will represent by first order transfer function right. So, that similarly when we will come to that this is your V T. So, V T upon V F also general side also we will see.

So, that is V F S upon V R S is equal to K E upon 1 plus S T E. This is exciter part. So, time constant of modern exciters are very small, very small right.

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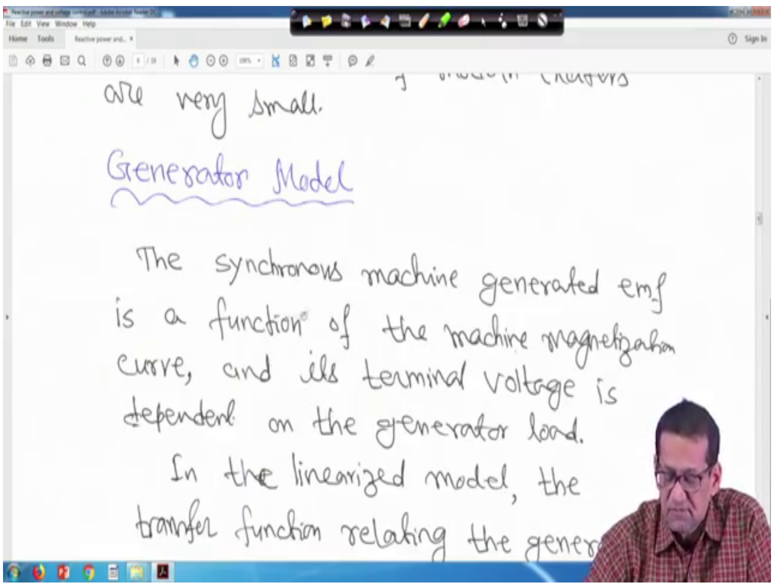

Now generator model for this case. So, the synchronous machine generated emf is a function of the machine magnetization curve and it is you are what we call terminal voltage is dependent on the generator load right. In the linearized model the transfer function relating the generator terminal voltage to its field voltage can be represented by a gain K G and a time constant T G.

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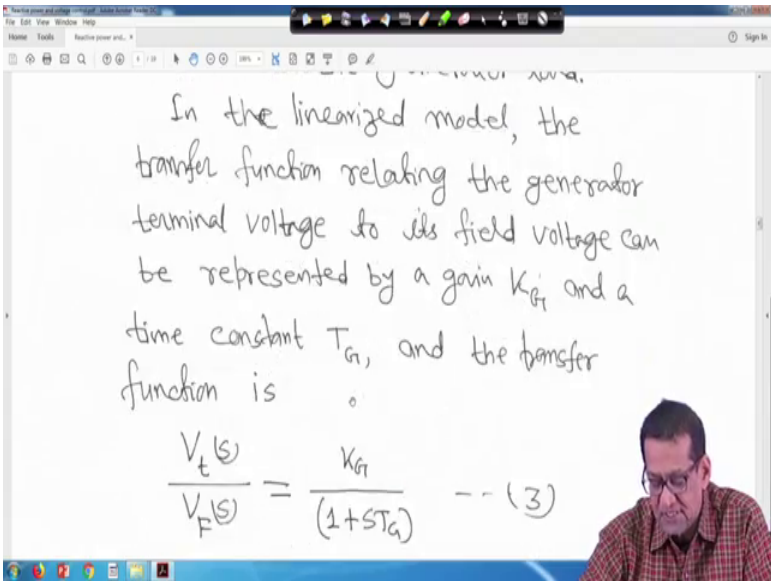

So, it is again a first order transfer function. So, V t S upon V F S is equal to K G upon 1 plus ST G. So, this is equation 3 are all simplified thing, right.

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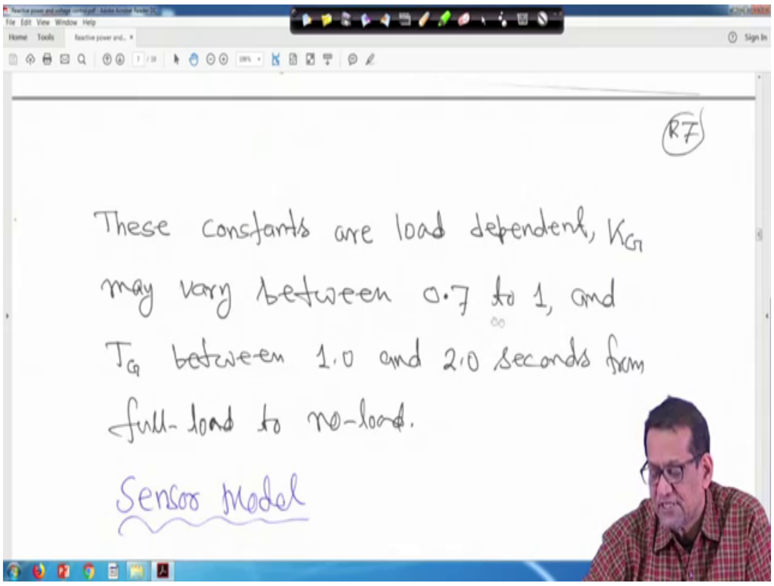

So, these constant are load dependent, K G may vary between 0.7 to 1 and T G between 1 to 2 seconds right from full load to no load.

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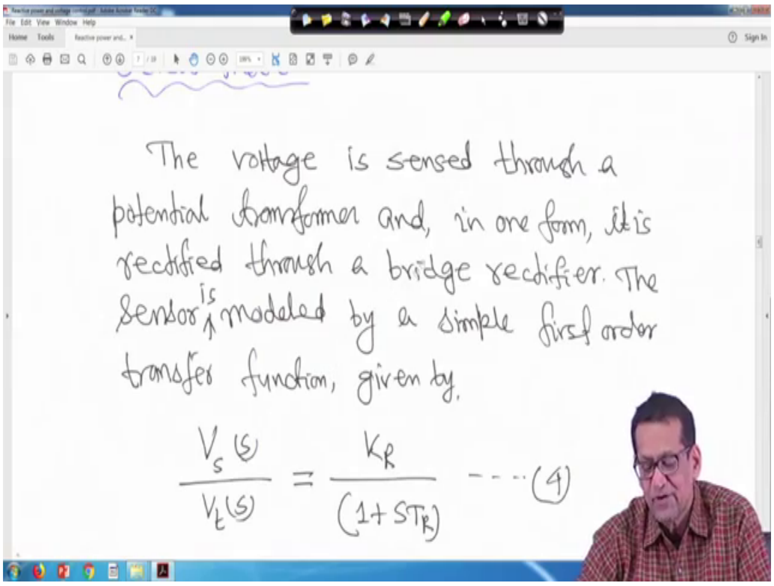

So, next one sensor is there. Sensor means that is your voltage is same through a potential transformer, right. So, and in and in one form it is rectified through a bridge rectifier. The sensor is modelled by a simple first order transfer function given by V S S upon V T S is equal to K R upon 1 plus S T R. This is equation 4, right. So, all these components we are actually representing by first order transfer function with some gain, right.

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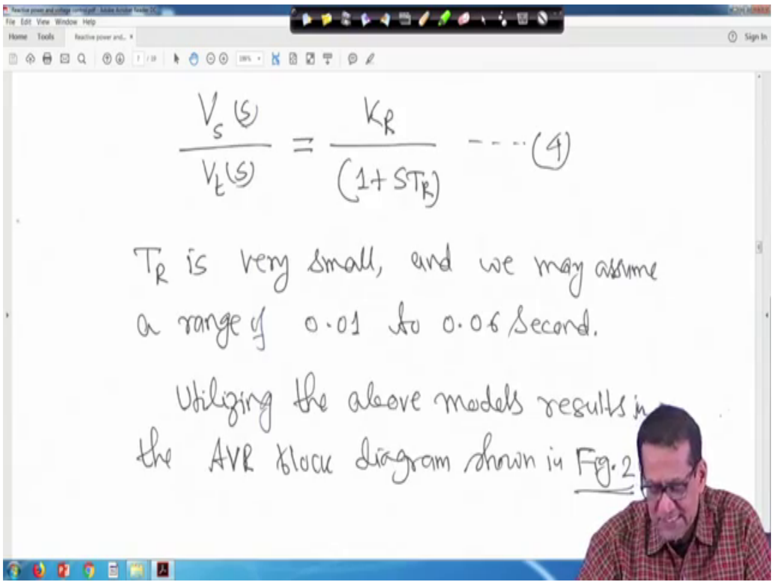

T R is very small and we may assume a range of 0.01 to 0.06 second, right. That is why that is why here if you look into that a simplified model of course the time constant are very small compared to your time constant of your governor turbine and power system, right.

So, that is generator when you considering that load frequency control that is why these two will be decoupled because when AGC action actually starts before that a time constant is so small, their dynamic that is why your what you call dynamic part disappear before that AGC things starts because time constants are very small. So, utilising the above models result in the AVR block diagram shown in figure 2.

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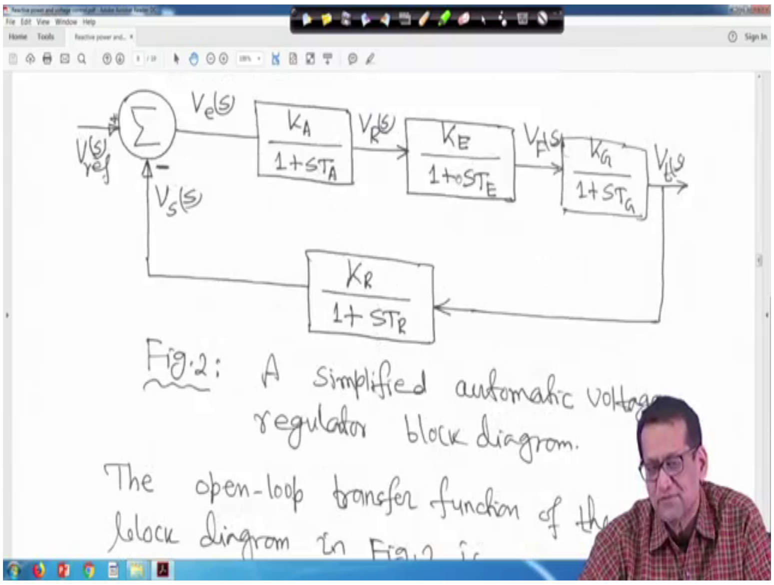

So, this is a simplest block diagram that only this type of thing already you have studied in your 3rd year Control System Engineering course right.

So, this is your K A upon 1 plus S T A amplifier, this is K E upon 1 plus S T E, the exciter transfer function, this is K G upon 1 plus S T G which relates terminal voltage of generator field voltage right where faster a transfer function and this is the sensor the potential transformer, it is sensing the voltage and rectifier, right. So, actually many studies you can find that T A actually is equal to 0. They consider simply K A and this one also T R is very small. So, they neglect T A and T R they neglect.

So, it will be simply K A and it should be simply K R, right. So, a simplified automatic voltage regulator block diagram. Now the open loop transfer function of the block diagram, the open loop transfer function of this one is simply we can write now K G S H S is equal to K A K E K G K R divided by 1 plus S T A 1 plus S T E 1 plus S T G into 1 plus S T R. This is actually open loop transfer function right.

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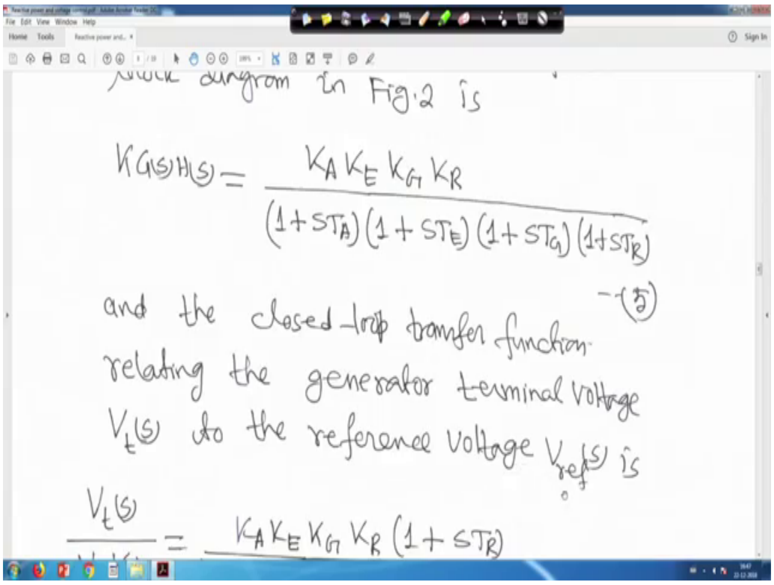

And the closed loop transfer function relating the generator terminal voltage V t S to the reference voltage V ref V reference that is V t S upon V reference actually is equal to if you try to find out the transfer function if you try to find out the transfer function V t S upon V reference, right.

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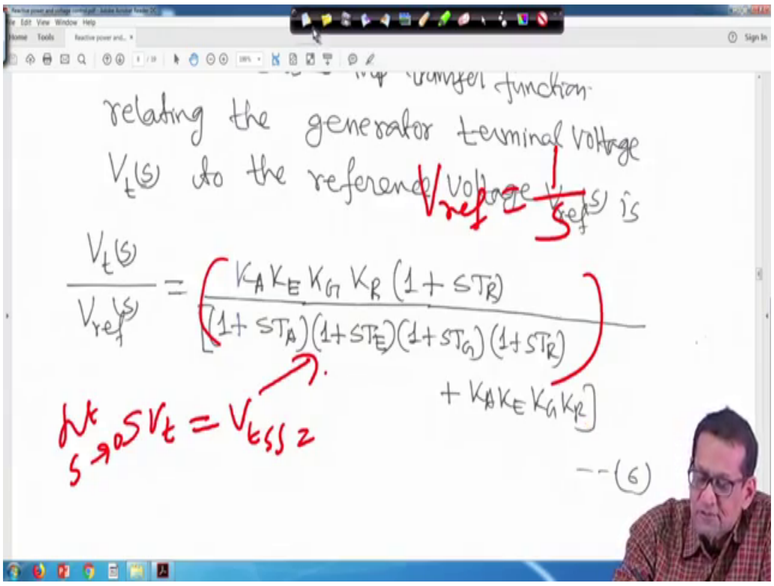

Then you will get that K A K E K G K R into 1 plus S T R divided by 1 plus S T A into 1 plus S T E into 1 plus S T G into 1 plus S T R plus K A K E K G K R. This is equation 6, right. So, this is the transfer function.

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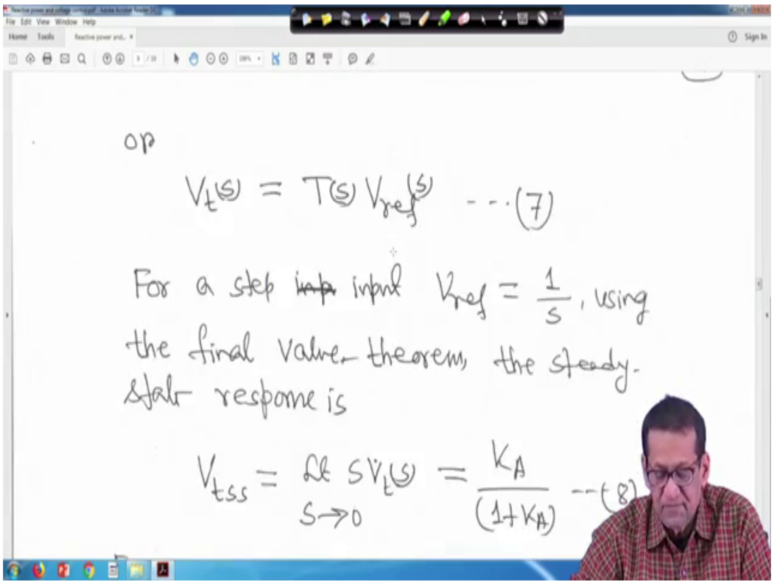

Now, or we can write V ts is equal to T s into V reference s that is 7. So, T s is equal to this whole transfer function this T s the whole thing right hand side. So, for a step input that is V reference could be taken as 1 upon s using the final value theorem, the steady state response will be V tss limit s tends to 0 S V t s that will become K A upon 1 plus K A.

So, this is actually this one actually we are taking that step response input that V S V reference is equal to 1 upon s, right. So, if you take V reference is equal to one upon s the left hand side will become SV t is equal to that whatever is there in the right hand side, this is equal to this one. Therefore, limit s tends to 0 right is equal to your V tss. So, put here everywhere s is equal to your what you call 0, right. If you put everywhere s is equal to I mean just put s is equal to 0 everywhere, so whatever it whatever your things will come right that your in this expression, right.

So, whatever you will get that is your s is 0, s is 0, s is 0. So, it will be 1, right. Here also is K A K E K G K R, here also K R K G K G K R. So, just hold on therefore, this one if you do so that T S is equal to V reference S, it will become actually it will be approximately your K A upon 1 plus K A, right V T steady state here right. So, if you put that if you put that your V reference is equal to 1 upon S.

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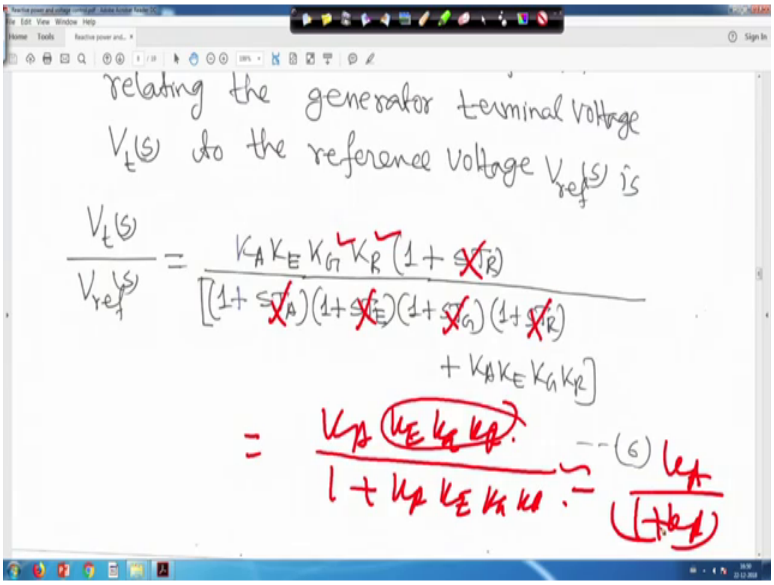

So, actually I am making it for you that if you make S tends to 0, so this term gone, this is gone, this is gone, this is gone and this is gone. So, this is actually you are K A, then K E, then K G, then K R right divided by your all these things S is equal to 0 1 plus K A K E K G K R, right. So, I mean it is actually K into K E K J, your K E your what you call K E K A K E K G K R divided by 1 plus K A K E K G and K R, right. For the sake of understanding for example if we take this K A K E your this approximately it is K A upon 1 plus K A, right.

So, if you put here that is why we are writing here that your that your for a step response V t s steady state will be your S VT your what you call is equal to 1 plus K A upon 1 plus K A, right. So, based on this whatever we wrote that K A K E K G sorry K A K E K G K R and this is also your K E K G K R, right.

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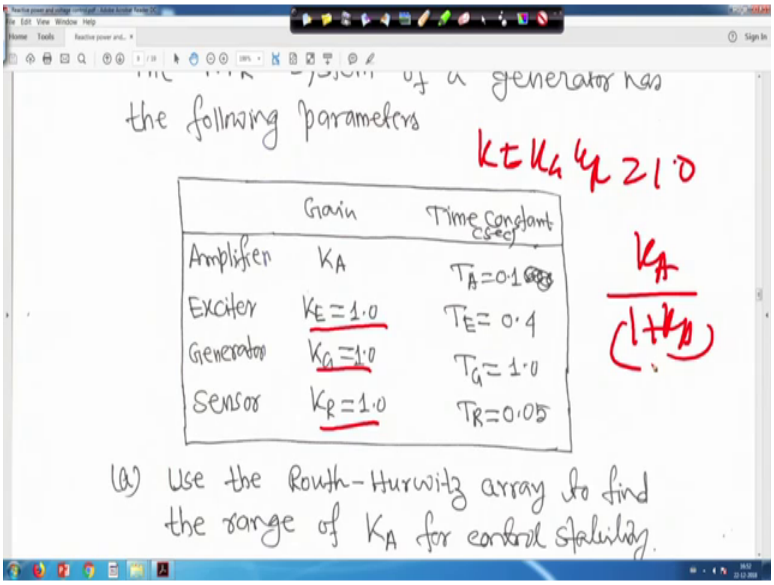

So, now this one your what you call if you take this example because if you look into that that in general you will find that K E K G and K R this is actually all are unity. That is why there we have taken K E K G and K R is equal to 1.0.

These are all 1, right. We are here we have taken 1, but approximately therefore they have all are 1 1 1, right. So, in that case that is why it is coming K A upon 1 plus K A right that is V tss steady state value. Now now suppose this a that gain K A is unknown K E K G K R value all are unity and T A is point 1, T E is 0.4, T G is 1 and T R is equal to 0.05, right. So, now it is given that you have to find out that use the Routh Hurwitz array to find the range of K for control stability.

The amplifier gain is K is an amplifier gain is set to K A is equal to 10, find the steady state response. So, Routh Hurwitz calculated here you know this right you know this, but little bit we will brush up our memories.

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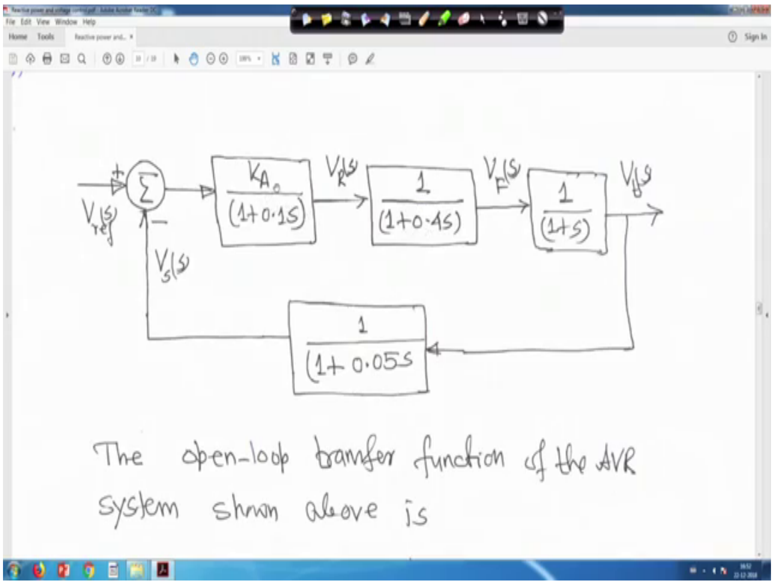

So, now this is the value. All these values are substituted and K is unknown. K is unknown right, but all other values are substituted in this block diagram.

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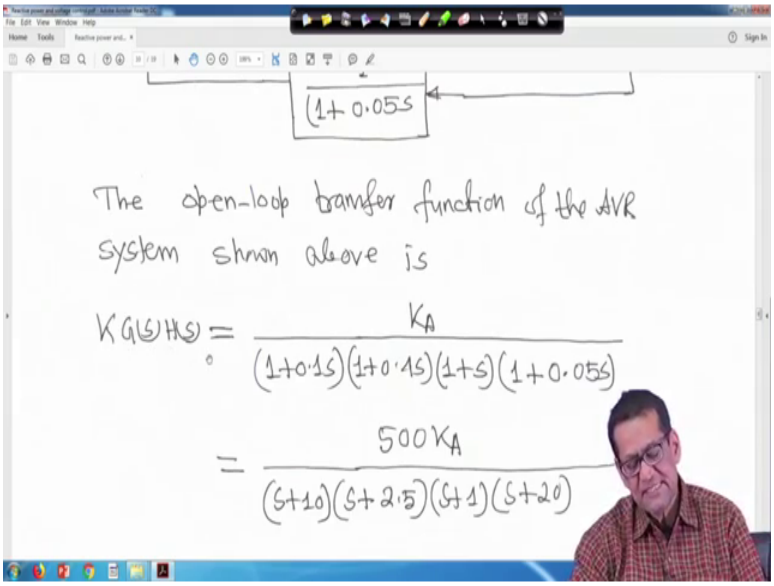

Now, the open loop transfer function of the AVR system shown above is that open loop transfer function K GS HS will be K upon 1 plus 0.1 S into 1 plus 0.4 S into 1 plus S into 1 plus 0.05 S, right.

So, if you just simplify like this is equal to will come 500 K A upon S plus 10 into S plus 2.5 into S plus 1 into S plus 20, right.

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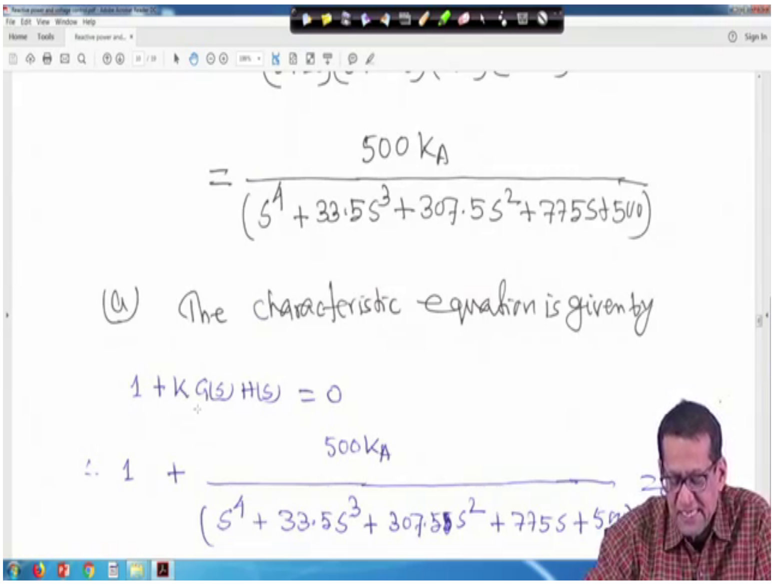

Or if you multiply all this will be 500 K A divided by S to the power 4 plus 33.5 S cube plus 307.5 S square plus 775 S plus 500, right. So, now characteristic equation you know that is given by 1 plu K G S H S is equal to 0. Therefore, this is the characteristic equation 1 plus 500 K a divided by S to the power 4 plus 33.5 S cube plus 307.5 S square plus 775 S plus 500 is equal to 0.

Now, after getting this characteristic equation we will go to Routh Hurwitz criteria. So, before that before going to directly going to that let us brush up our memories regarding Routh Hurwitz criteria, right.

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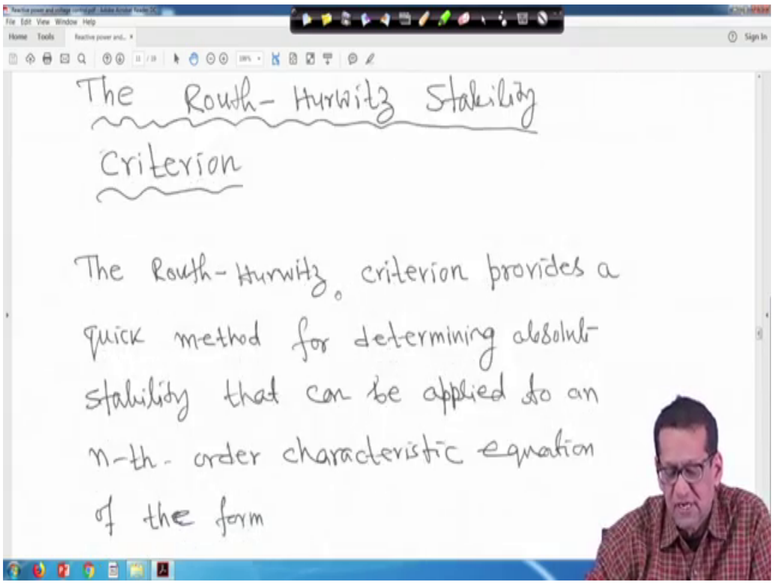

So, the Routh Hurwitz stability criteria then we will go to the problem. So, the Routh Hurwitz criterion this we have this we have studied in your 3rd year control system engineering. So, very simple thing provide a quick method for determining absolute stability that can be applied to an nth order characteristic equation of the form.

Suppose your characteristic equation is a n s to the power n plus a n minus 1 s to the power n minus 1 plus plus plus plus a 1 s plus a 0 is equal to 0. This is my characteristic equation. It is nth order polynomial, right

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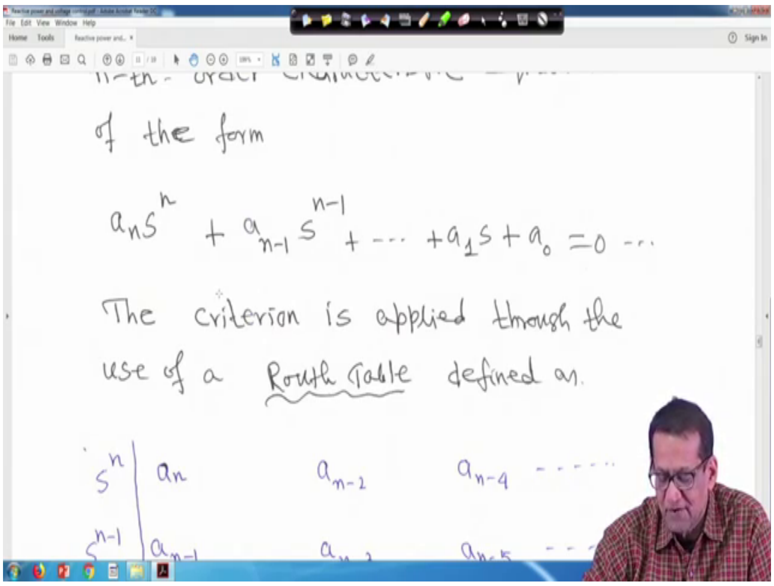

So, the criterion is applied through the use of a Routh table defined as that s to the power n. So, this is a n, then your this will be a n minus 2 a n minus 4 and so on, right similarly for s n minus 1, it will be a n minus 1, a n minus 3, a n minus 5, right. So, a a s n and these two you written. So, s n minus 2 that will be your what you call that you are b1. So, b1 you know that will be a n minus 1, you know that row just I have written at the at the bottom a b 1 will be a n minus 1 into a n minus 2 minus a minus a n into a n minus 3 divided by your what you call that your a n minus your what you call 1, right.

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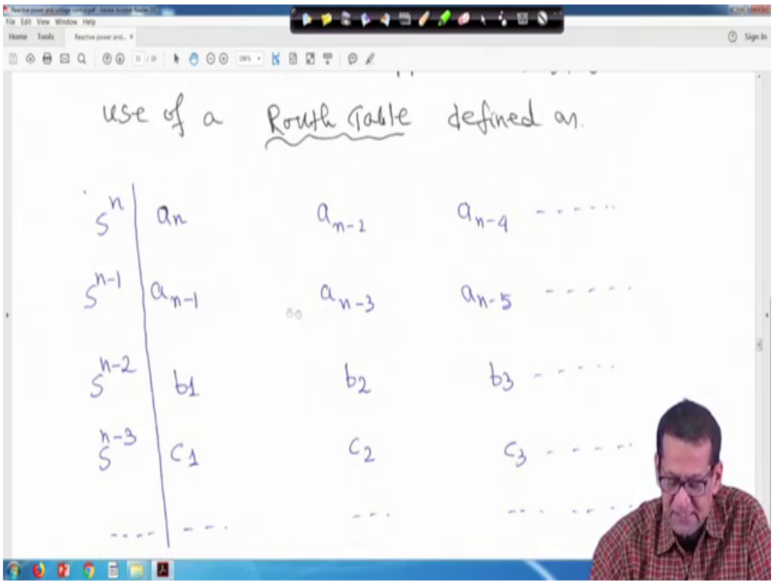

So, that means that b 1 b 2 b 3 c 1 c 2 c 3.

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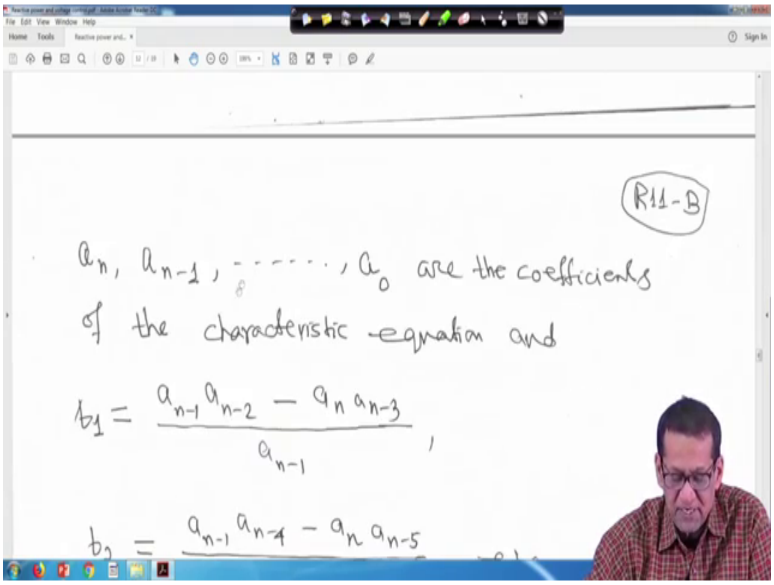

Now, your what you call that a n is equal to your a a n a n minus 1, a 0 are the coefficient and of the characteristic equation and b 1 we you know this I told you that it is a n minus 1, your into a n minus 2 minus an an minus 3 divided by an minus 1. So, this is this is my b 1, similarly b 2 will be also from this equation. You know that from this equation b 2 will be your an minus 1 an minus 4 minus an into an minus 5 divided by an minus 1 etc right. This way computation will go.

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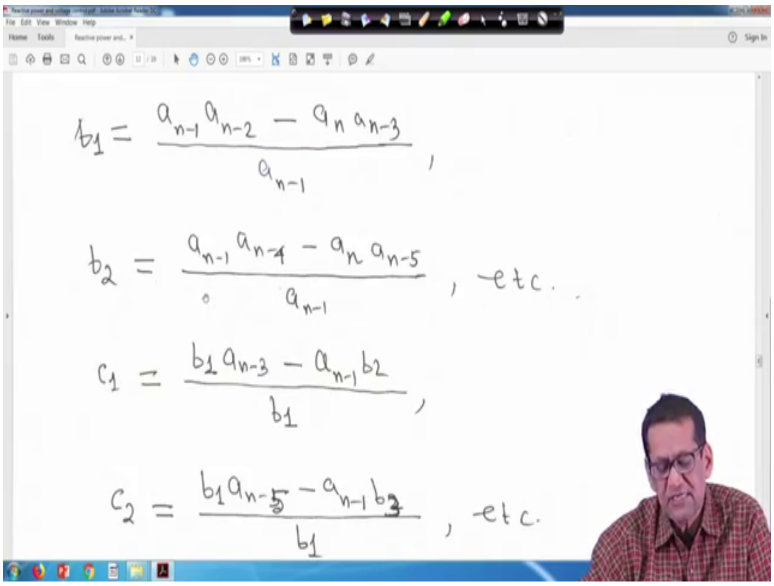

Similarly, for the 4th row that is your c 1 c 2 also in similar way you have to compute. So, c 1 will be b 1 a minus a an minus 3. Now c 1 will b 1 an minus 3 minus b 2 an minus 1 divided by b 1, right.

So, similarly your c 1 will be b 1 an minus 3 minus d 2 an minus 1 divided by b 1 c 2 is equal to b 1 an minus 5 minus an minus 1 b 3 upon b 1 etc right. This way computation this you know now calculations in each row are constant are continued. Sorry your until only zero elements remain, right.

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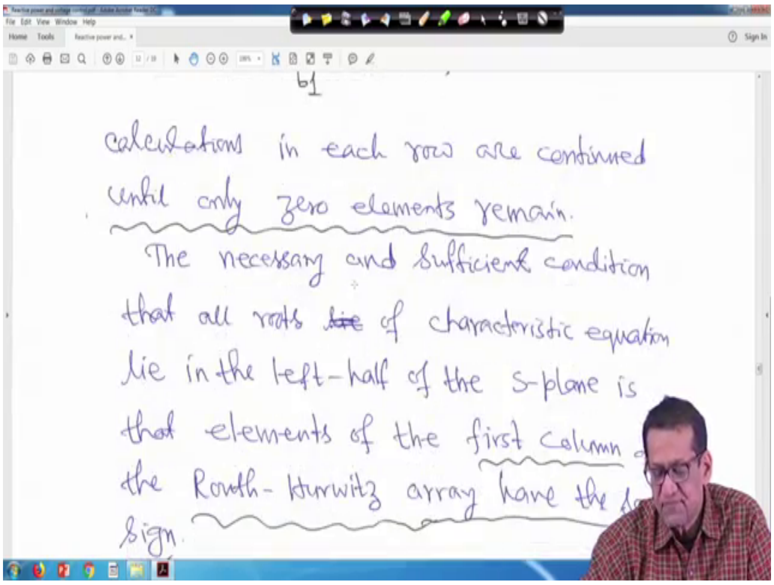

The necessary and sufficient condition that all roots of characteristic equation lie in the left half of the s plane is that elements that that mean is system will be stable. If all their roots will real part of the roots all the roots lie on the left half of the s plane that is your real part should be negative, right.

So, that elements of the first column of the Routh Hurwitz array have the same sign right.

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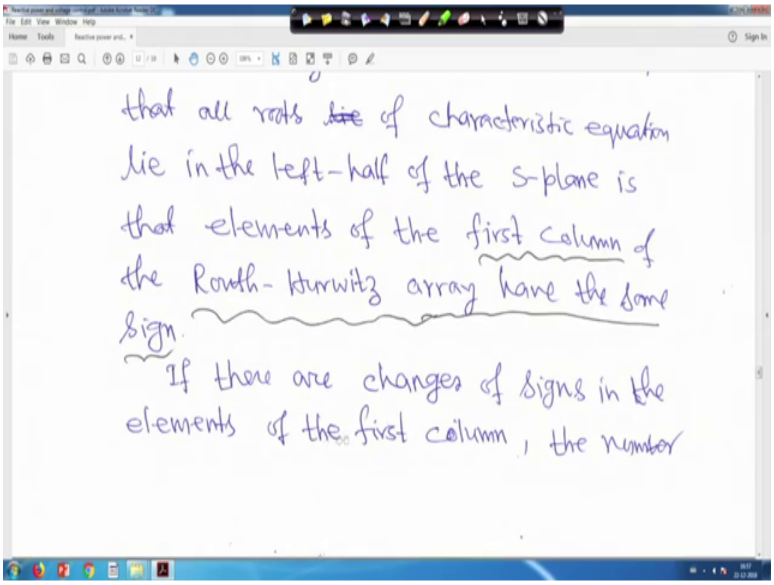

If there are changes of signs in the element that we know of the first column, the number of sign changes indicates the number of roots with positive real parts right. This you know.

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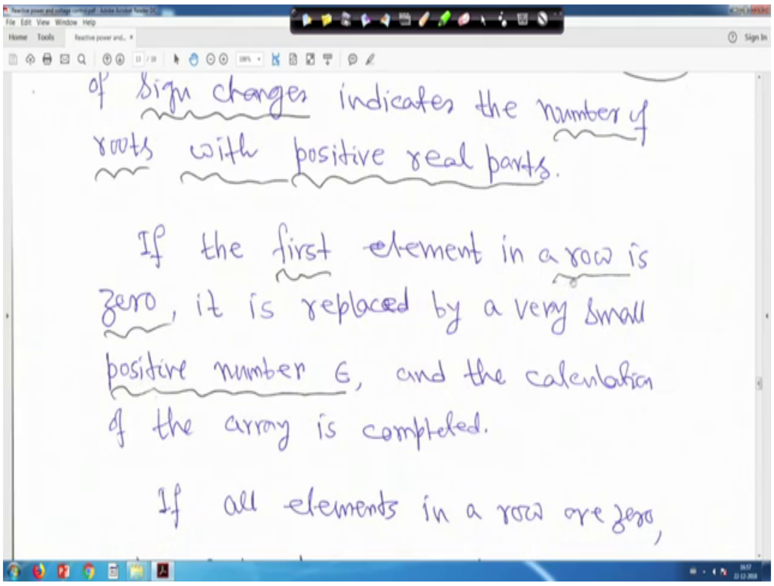

If the first element in a row is 0 right, so it is replaced by very small positive number say epsilon and the calculations of the calculation of the array is completed, right.

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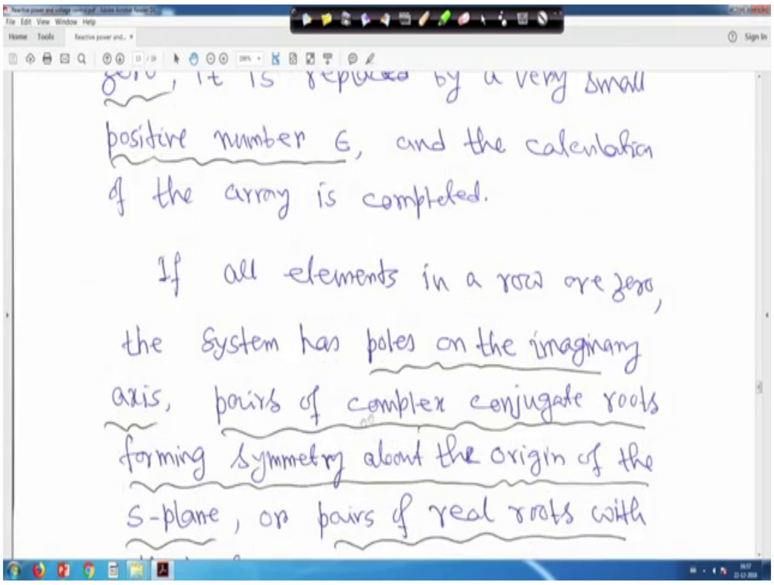

If all elements in a row are 0, the system has poles on the imaginary axis that you know pairs of complex conjugate roots farming symmetry about the origin of the s plane or pairs of real roots with opposite signs.

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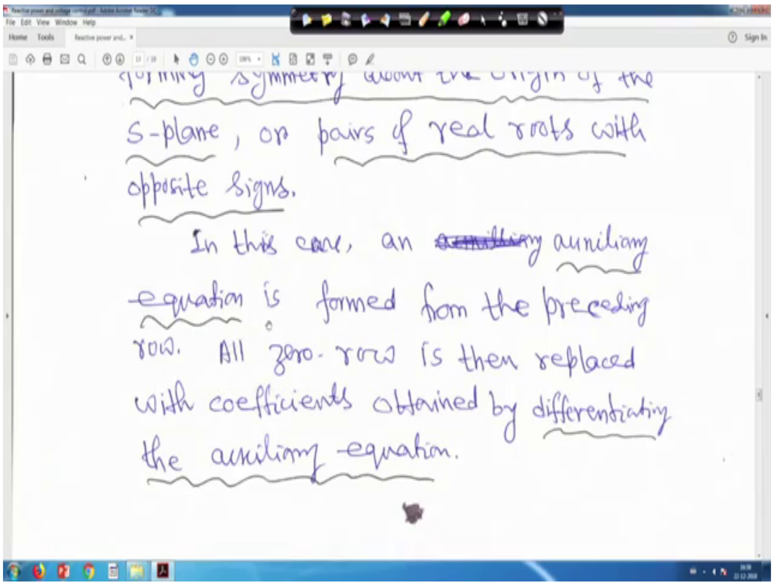

So, in this case an auxiliary equation is formed, right. So, if it happen, so an auxiliary equation is formed from the preceding row. All zero row is then replaced with coefficient obtained by differentiating the auxiliary equations. So, all these things you have what you call that you have studied in your 3rd year Control System Engineering.

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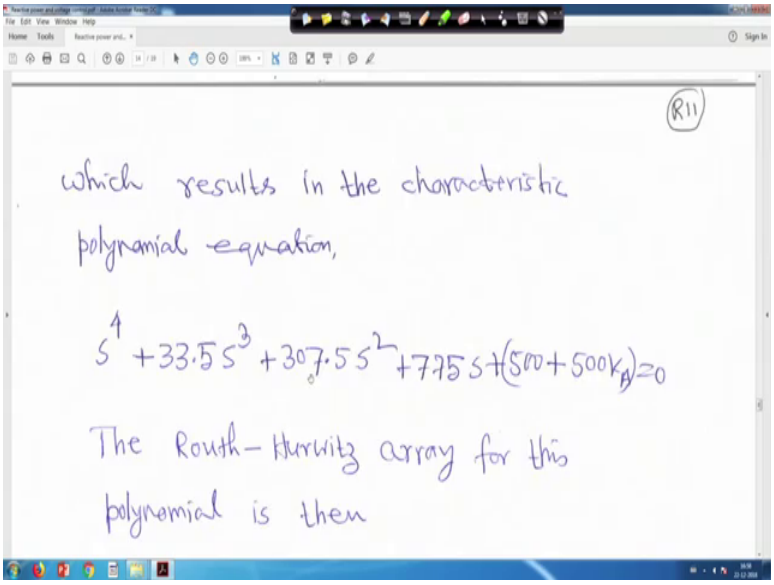

Now, if we go to Routh Hurwitz array therefore now we are coming which results in the characteristic polynomial equation. So, in that case it will be s to the power 4 plus 33.5 s cube plus 307.5 s square plus 775 s plus 500 plus 500 K A is equal to 0.

Now, Routh Hurwitz array for this polynomial for this polynomial is then make it will be S 4 coefficient is 1, then it is s square 307.5 and s to the power 0. So, 500 plus 500 K A, right. Similarly SQ this one also 33.57 75 and 0.0. Now b 1 b 2 b 1 is 280.

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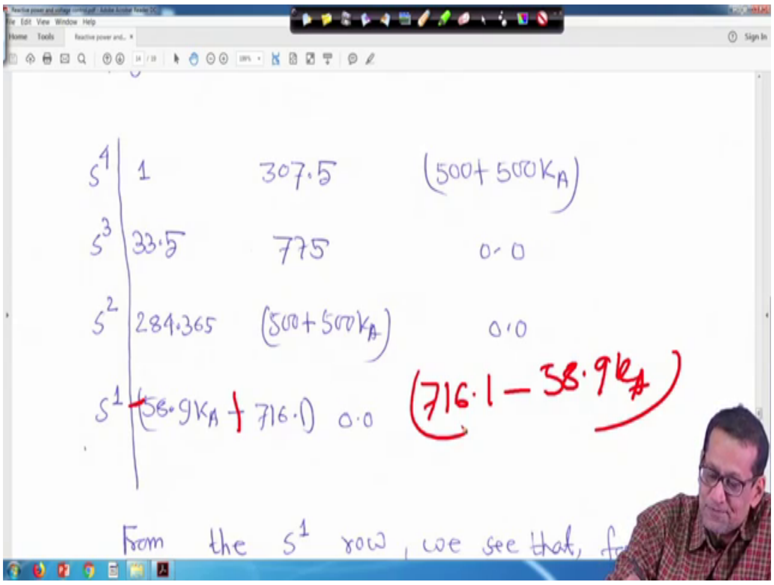

Similarly if you compute it will be 284.365 and b 2 will be 500 K A, b 3 will be 0 here one sign mistake I have made. I am correcting it. Actually this should plus this should be minus right. That means, it should have been actually 716.1 minus 58.9 K A, right. After scanning this it came to my mind that one it was when I am writing it by mistake I made this one, it will be 716.1 minus your 58.9 K A, right.

So, if you now this is your corrected right. So, it will be plus 716 and minus 58.9 K A. Now if it is plus if it is minus this your what to call that you have to make all these elements is positive, but this one if you make positive now all the rows, right.

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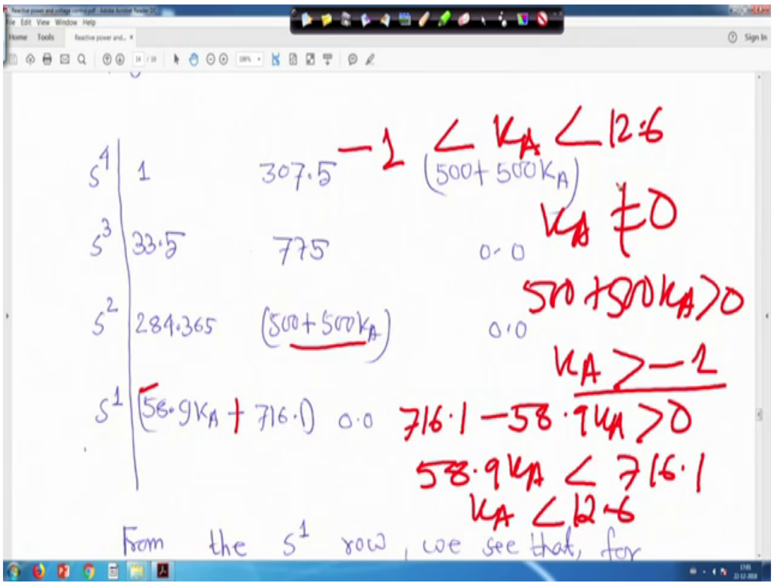

For example that will be 500 plus 500 K A. It will be greater than 0, it has to be positive. That means, now your K A right greater than minus 1, this is one condition right. Similarly this one you are what you call that your 716.1 this is plus actually minus 58.9 K A that has to be greater than 0 right. That means, you are if I make it like this in other way that 58.9 K A less than actually 716.1. That means, if you simplify that K A will be less than 12.6, right.

That means, that this K A value for stability it will like minus 1 K A greater than minus 1 your less than 12.6, but K A not is equal to 0, right. If K A is equal to 0, then whole system that your nothing will happen right.

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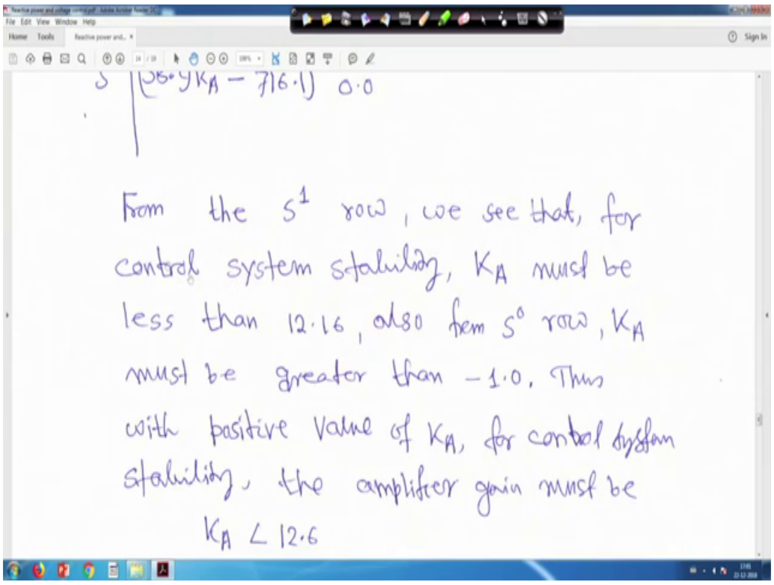

So, if we do, so if you do then for from the s 1 row we see that for control system stability K A must be less than 12.6.

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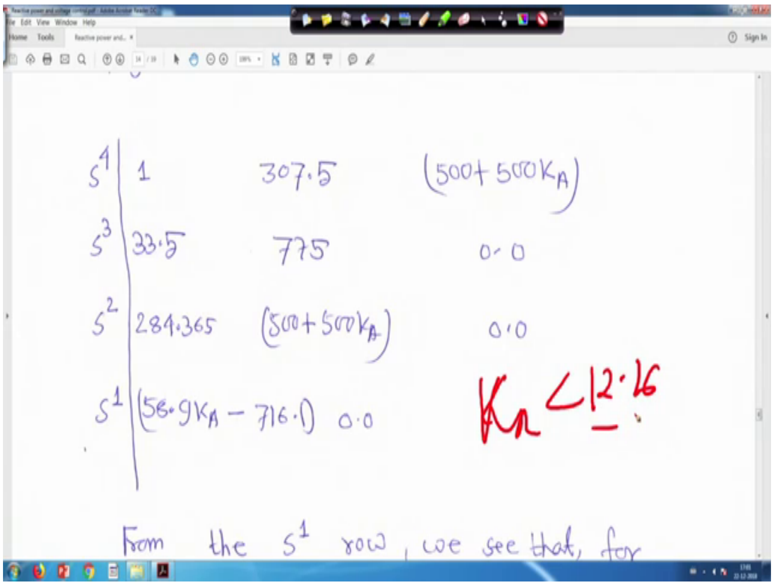

It is not 12.6 it is not 12.6 it was actually K A actually less than 12.16 not 12.6, right.

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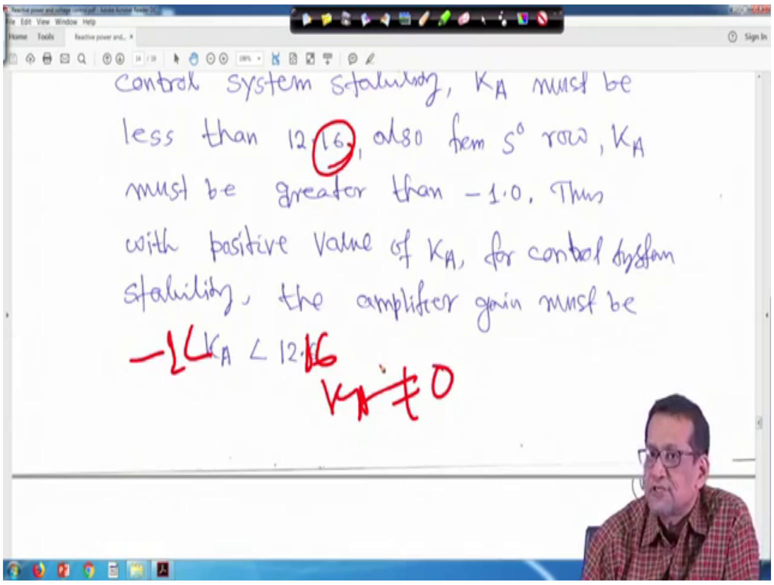

So, also from this S 0 row K A must be greater than minus 1. Thus we positive these thing value of K A for control systems ability the amplifier gain must be K A less than this thing, but here also I can add this one that your minus 1 your K A greater than minus 1 less than 12.16, this is 12.16 in by mistake I have written this 6. It is 12.16, right.

So, it will be, but at the same time K A not is equal to 0, right. So, for k is equal to 12.6, right

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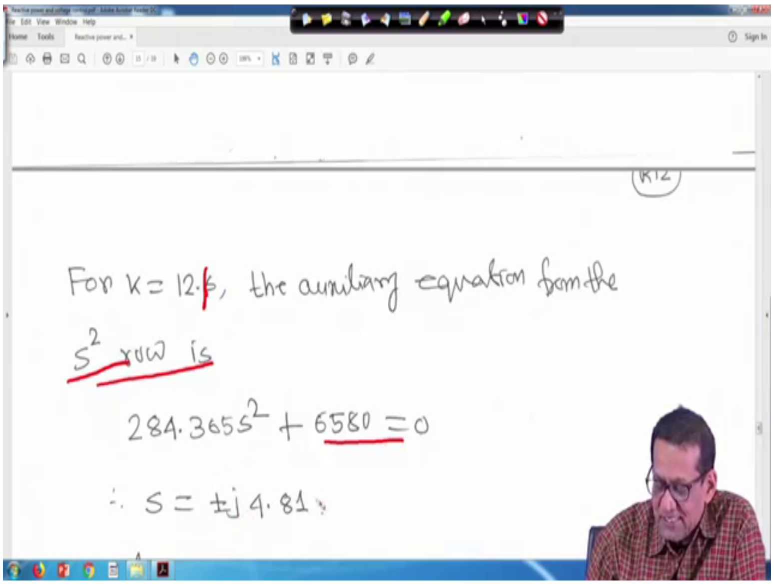

It is just check it is it seems 12. 16. Just check it right. In many places I have written 12.6 perhaps it is 12.16. I do not have calculator here to calculate right, otherwise ai should have corrected it here, but just take it nothing it is nothing actually.

So, this row if you look into this row it will be 284.365 s square plus 6580 is equal to 0 that means, ac will be become plus minus j 4.81 right. That means, roots are lying on the imaginary axis this that is for k is equal to just check again I am written 12.6. Just check whether 1 6 or 12.6 right just check. I do not have calculator here. So, we have a pair of conjugate poles on the j omega axis and the control system is your marginally stable right. So, this is the thing.

So, the closed loop closed loop transfer function of the system that is your figure, I have given page number r 10, right.

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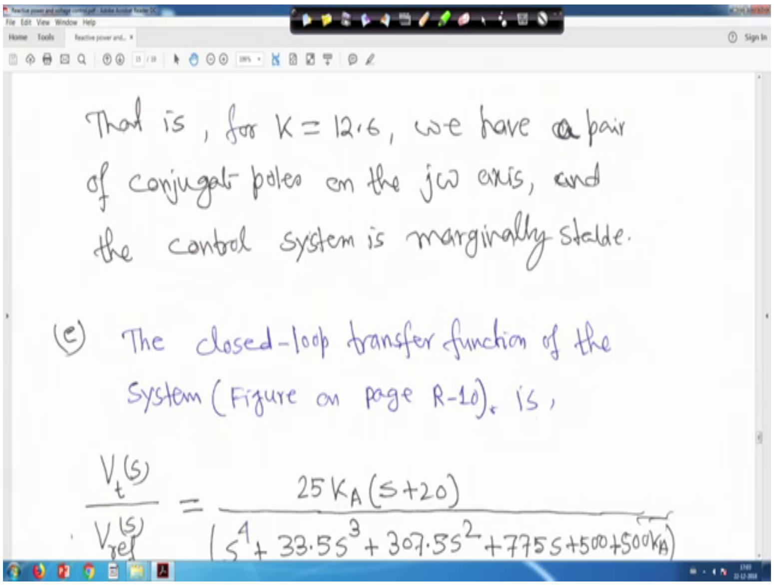

So, that same figure, same block diagram if you find out that V ts upon V references s the 25 K A S plus 20 upon all these terms, right.

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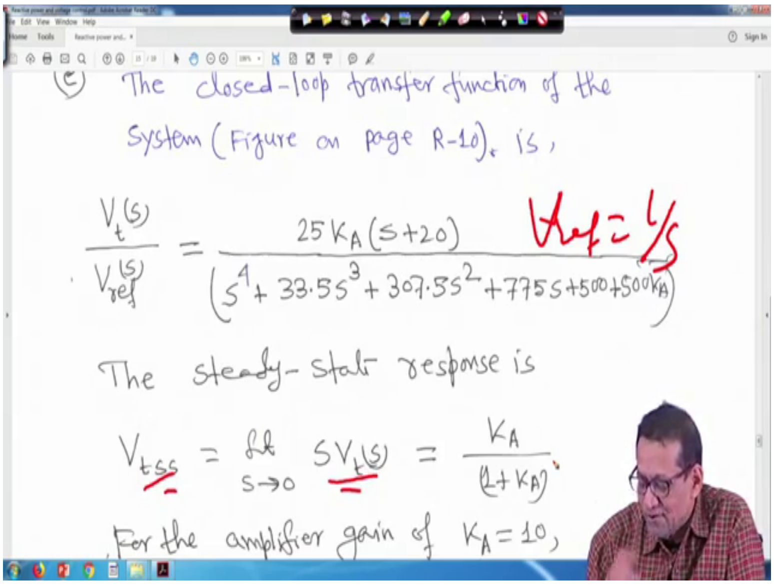

So, a steady state V reference is equal to your 1 upon S step input V reference is equal to 1 upon S, the step input. So, if you find out V TS as will be s tends to 0 S V t s it will become 1 K A upon 1 plus K A, right and it is given that what for K A is equal to 10. What is the steady state value?

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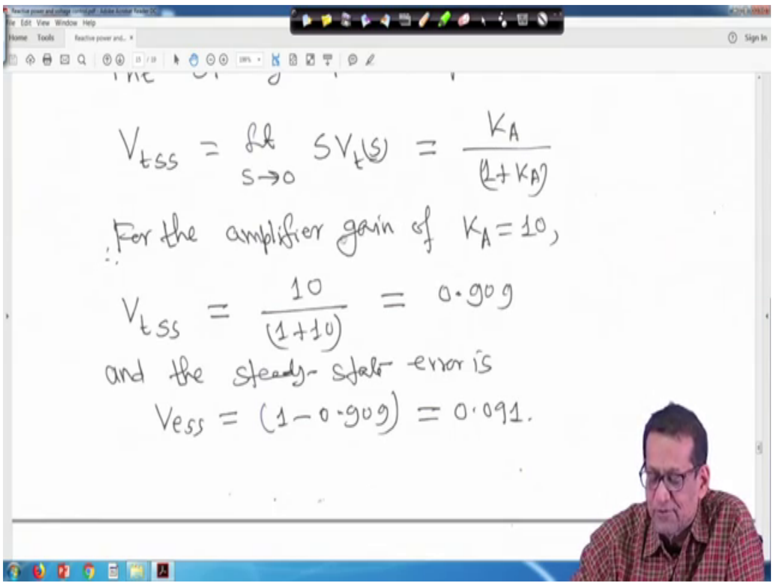

So, for K A is equal to 10, it will be 10 upon 1 plus 10. So, 0.909 right that is steady state V t s and the state error will be because it is 1 per unit was that voltage. So, 1 minus 0.909. So, 0.091, so steady state error is quite high right. So, that is the thing. Only thing is that this K A value in the previous example you check whether it is 12.6 or 12.16. So, our next video lecture I will rectify that one, right. So, otherwise everything is all hope I do hope that all calculations are correct right.

Thank you very much. We will back again.