Electrical Machines

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Lecture 24: DC Motors: Speed Control (Shunt and Separately Excited Motor)

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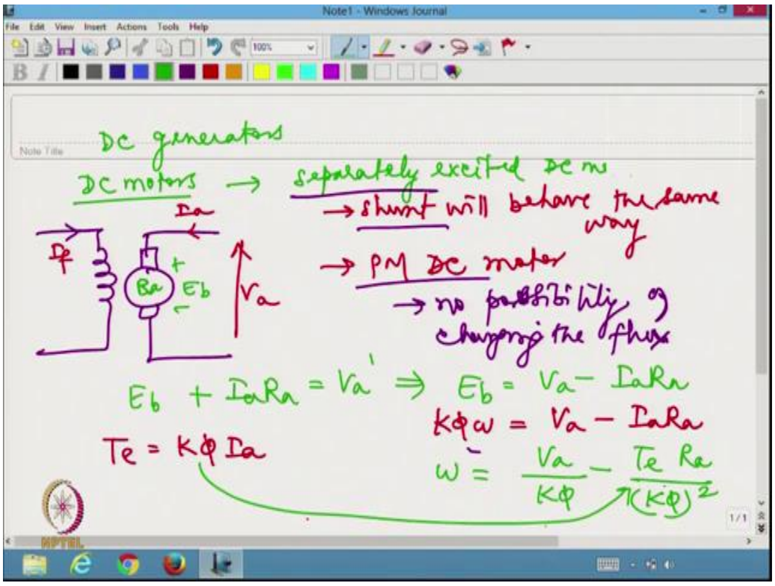

Until now, we had seen the different types of DC generators; we just started on the DC motors. So, in DC motor mainly what we had discussed was separately excited DC motor. But in separately excited DC motor, although we said magnet or the electromagnet will be separately excited, so we may show it somewhat like this. This is my armature and this is the field and field is being separately excited. So, this I_f, whereas this is going to be I_a, which is flowing from my armature supply.

Shunt is almost similar, so, shunt will behave almost in the same way; and I can say permanent magnet DC motor is also almost similar except that it will have no possibility of changing the excitation, no possibility of changing the flux that is the major difference; otherwise all of them behave almost similarly. What I am trying to say is separately excited DC motor, shunt motor as well as permanent magnet DC motor all three of them behave very similarly.

We also talked about the Torque Speed Equation, if you may recall, we said, if we area applying V_a here, this is the back EMF and inherent resistances Ra. So, I can write Eb plus

$I_a R_a$ equal to V_a. So, I should be able to write $E_b = V_a - I_a R_a$. So, I can say $K\phi\omega = V_a - I_a R_a$, but we also said $T_e = K\phi I_a$. So, I can write this equation now as $\omega = \frac{V_a}{K\phi} - \frac{T_e R_a}{(K\phi)^2}$.

So, torque speed relationship is basically a linear relationship which I can plot somewhat like this.

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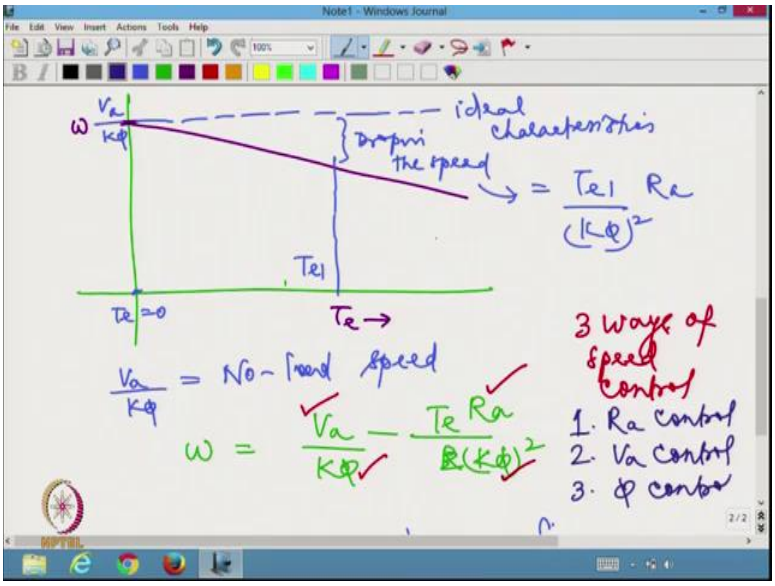

If this is the torque speed plane on one side I am showing ω on other side I am showing T_e. So, if I try to plot, this will be straight line characteristics. If I had had the armature resistance to be zero, so this would have been the ideal characteristics for the motor.

But because if I have an armature resistance there is going to be some drop in the voltage which will also cause a drop in the speed. So, if I may call this point as $\frac{V_a}{K\phi}$, which is corresponding to the torque equal to 0 point. So, $\frac{V_a}{K\phi}$ I can call as the no load speed that is the speed when torque is zero. But as I have more and more current drawn, or the torque demanded from the load side, I am going to have at this point so much of drop in the speed.

So, this is the drop in the speed. So, if I say that this is T_{e1}, I am going to have T_{e1}, corresponding to this the drop in the speed will be $\frac{T_e R_a}{(K\phi)^2}$. So, I have totally three variables that I can change, either V_a I can change or ϕ, I can change or R_a I can change. So these are the three ways of speed control in the DC motor. So, the first method is R_a control, the second method is V_a control and the third method is flux control. So, these are the three methods of DC motor speed control.

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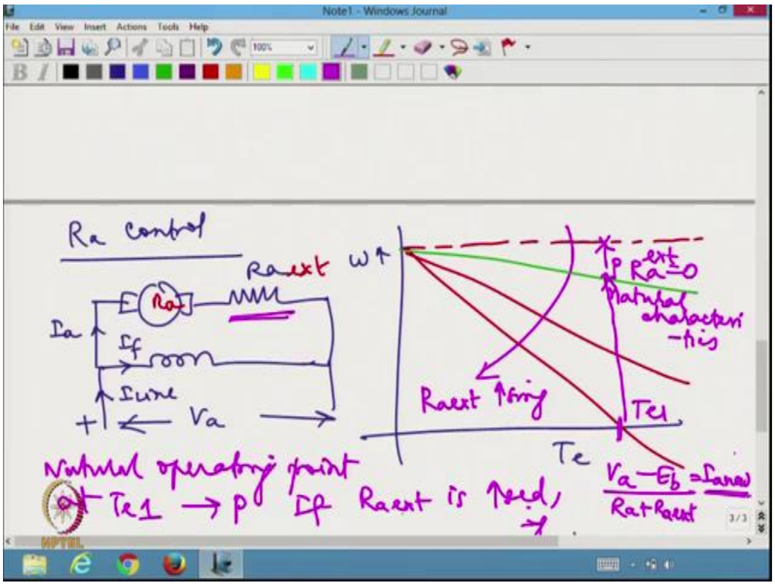

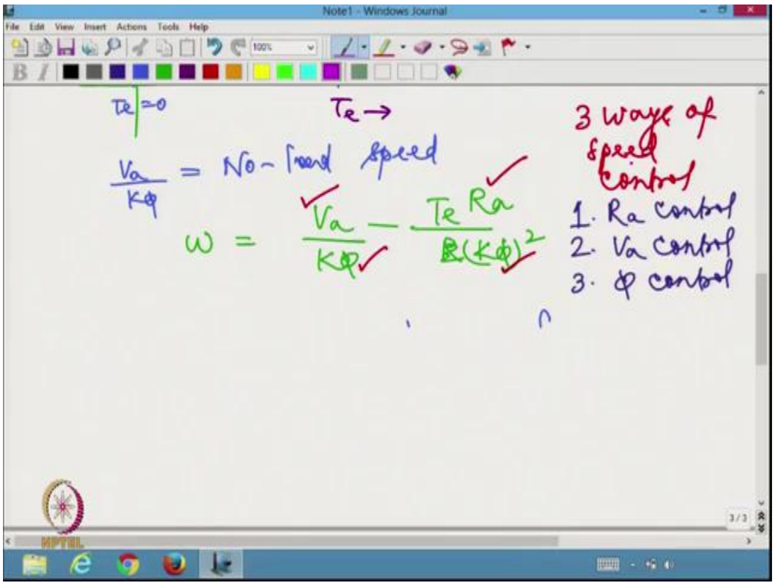

So, in armature resistance control that is R_a control. We are going to include a resistance in series with the armature. May be the field is also connected here, it does not matter. May be it is a shunt excited machine and I am connecting V_a here. So I am going to have an overall current which is the line current flowing here, part of it goes as field current, rest of it goes as armature current.

So, if I try to plot, the speed torque characteristics, this is ω, this is T_e, so I am going to have may be the natural characteristic somewhat like this. If the machine had been ideal, I would have had the characteristic somewhat like this. Now I am going to increase more and more resistance, so this is $R_{a\text{int}}$, this is R_{aext}. So, if I include more and more resistance, more and more drop would take place.

So, I am going to have this as Ra external increasing. This is R_a equal to 0, R_{aext} is 0. So, I am going to have actually, once R_a external is 0, this is the natural characteristic of the machine. But if I try to include more and more R_a, I am going to have more and more drop in the armature circuit resistance here, because of which the speed is falling more and more.

So, dynamically if I try to analyze this, let us say I am demanding a particular value of torque. May be I was under this operating condition P, so, natural operating point at T_{e1} is P, so, this is T_{e1}. So, this is the operating point P, this is the operating point P. So, now if I actually increase the resistance, if R_a external is increased now, what is going to happen is immediately I am going to see that the current that is flowing here, I_a will get decreased, because I have $I_{anew} = \dfrac{V_a - E_b}{R_a + R_{aext}}$. So, I_{anew} will be less than the original value of armature current.

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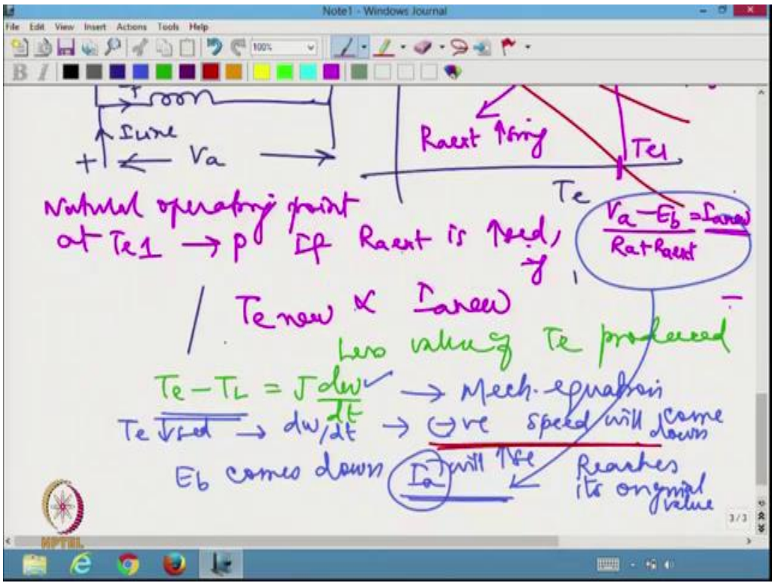

Because it is now less than the original value of armature current, what is going to happen now is, the torque that is produced is going to be proportional to I_{anew}. So, I am going to have less value of T_e produced. So, if I look at actually the speed, the speed is going to be $T_e - T_L = J\frac{d\omega}{dt}$.

Originally, T_e and T_L were balancing each other, so ω was actually at a steady operating point. Now, T_e has decreased, because T_e has decreased, I am going to have clearly the amount of speed that is actually offered, I am going to have $\frac{d\omega}{dt}$ being negative. If this is negative speed will come down. So, if speed comes down, then I am going to have back EMF is also going to come down. Because back EMF comes down from this equation I can say I_a will increase.

So, I_a increases and reaches its original value. So, you may see a small transient reduction in the speed that will essentially make the armature current increase and ultimately it will settle down at a speed which is less than the original speed. So, you are going to see that it will be able to offer the same torque.

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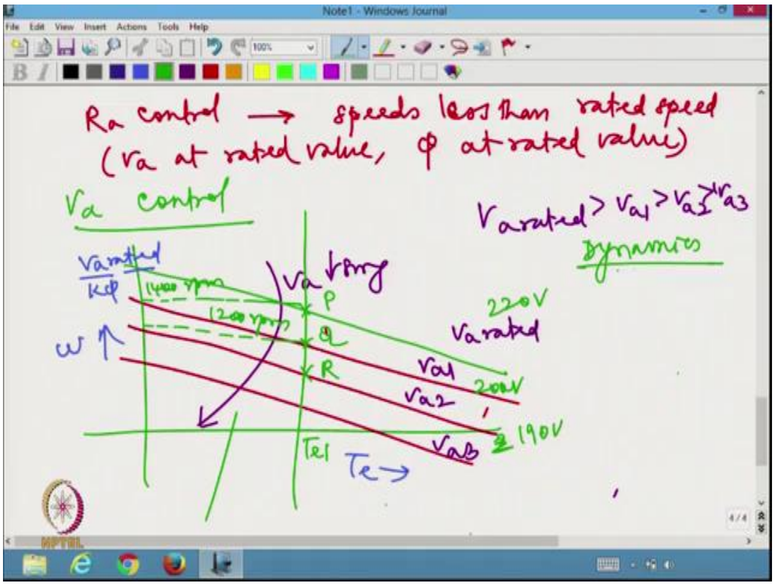

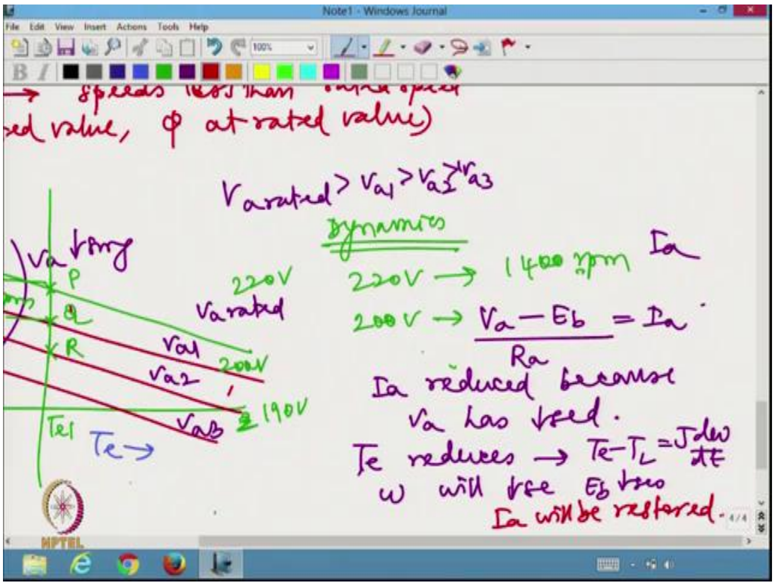

So, in general I can say R_a control will always result is speed less than rated speed, you can never go above the rated speed provided I am keeping V_a at rated value and flux is also at rated value, both are at rated value. So much so far, R_a control. Then next one, what we are going to look at this V_a control? So, in armature voltage control, what I am looking at is actually, I am going to have basically the voltage is normally applied, which is the rated voltage. So, let me call probably this as rated voltage. So, the speed I am going to get is $\omega = \frac{V_{arated}}{K\phi}$. If I have V_a itself change, without changing anything else further, this is going to be the operating characteristics. So, I am going to have this as V_a decreasing direction.

So, may be this is at V_{arated}, this is at V_{a1}, this is at V_{a2}, this is at V_{a3}. So, I will have V_{arated}, greater than V_{a1}, greater then V_{a2}, greater than V_{a3} and so on. So, as I decrease the volts, if I try to look at particular operating point, may be this is T_{e1}, at which the machine is operating. If I had applied 220 volts, maybe I would have gotten the operating point as P. If I apply say, 200 volt, I am going to get the operating point as Q.

If I apply, say 200 and rather 190 volts, maybe I am going to get the operating point as R and so on. So, we get lower and lower speed, you can see that the speed is originally probably 1400 rpm, may be this is at 1200 rpm and so on. So, I am going to have less and less speed. So, what happens dynamically when I reduce the voltage, when I actually I am operating a 220 volt, let us say, the speed was, we said 1400 rpm.

So, we are going to have 1400 rpm when we were working at, you know 220 volts, now I am reducing it to 200 volts, when I reduce the voltage to 200 volts, $I_a = \frac{V_a - E_b}{R_a}$. So, originally the current was I_a, now I am going to have, I_a reduced because V_a has reduced. Now, because of this torque reduces, so, $T_e - T_L = J\frac{d\omega}{dt}$, so, ω will decrease. Because ω decreases, I will have essentially E_b decreases; so, I_a will be restored to its original value.

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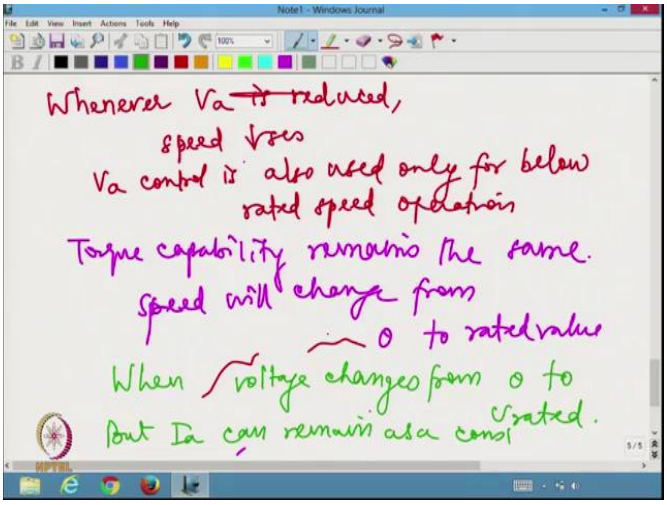

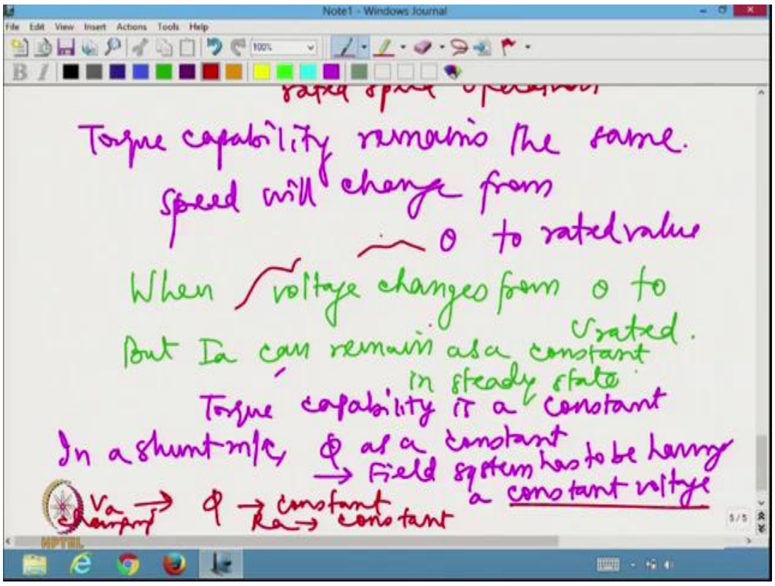

So, whenever I change V_a, whenever V_a is reduced, I am going to have essentially speed decreases. So, V_a control is also used only for below rated speed operation. Now, if I am talking about below rated speed and I_a restoring to its original value, torque capability remains the same, that means the speed will change from 0 to rated value, when voltage changes from 0 to V_{rated}. But, I_a can remain as a constant, no problem. But what we are talking about very clearly is in steady state.

Not during transient, during transient it will definitely vary. So, in steady state you can have I_a as a constant. So, torque capability is a constant. So much so far, armature voltage control, but please remember if it is shunt machine, we want to keep the flux as a constant. We want to keep flux as a constant, then that means, the field system has to be supplied separately.

Field system has to be having a constant voltage, it cannot have the same voltage, which you have given as a reduced voltage to the armature system, it has to be a constant voltage, if you do not have a constant voltage, flux cannot be a constant.

So, I would say whenever you are varying one of the values may be V_a you are changing. At that point you had to have flux as a constant and R_a also is a constant we do not want to vary everything then it will be very confusing. We do not to vary all three things at a time. If V_a is changing then we want to change, we want to keep flux and R_a as constants.

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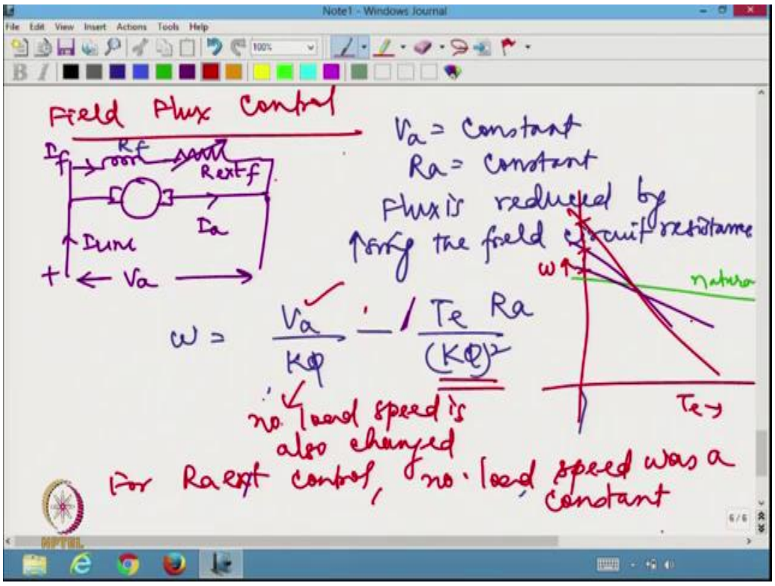

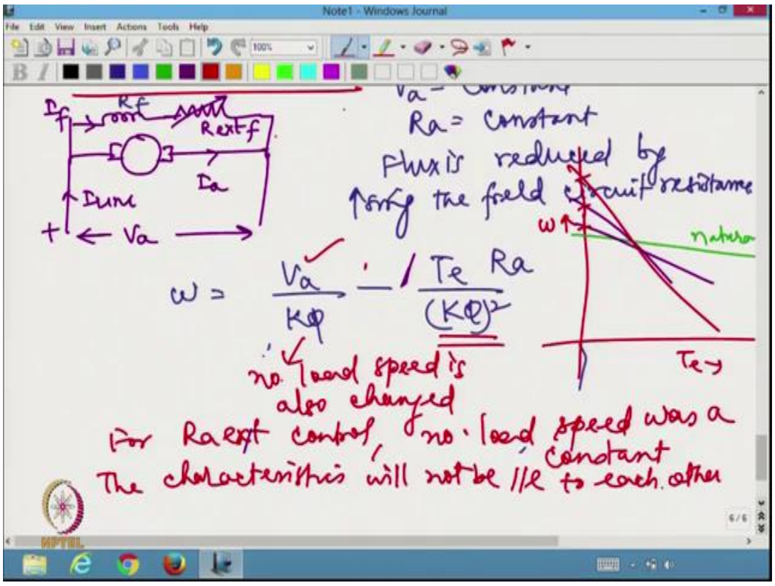

Now, let us try to look at the last type of control which is field flux control. So we are looking at field flux changing which means I am going to have here the armature I am going to keep very clearly V_a as a constant because I told you only one thing is changed at a time. Here is my field system I will put on external resistance and I would vary that so this is $R_{externalf}$ this is original R_f so this is going to be If and this is I_{line} and this is I_a.

So, what I am going to keep is basically V_a constant, R_a is also constant, flux is reduced. What I have is R_f that is very much there, I cannot include a negative resistance I can only include a positive resistance. So, increasing by increasing the field circuit resistance we are reducing the field flux. So, whenever I am going to have field flux reduced you think about it $\omega = \frac{V_a}{K\phi} - \frac{T_e R_a}{(K\phi)^2}$. So, you are going to have even for a constant value of V_a the no load speed is also changed. So, for R_a control or armature resistance control no load speed will change no load speed was a constant.

It did not change, so, we could see that it was starting from the same point when we drew the characteristics, but here, when we draw the characteristics, I say this is ω, and this is T_e. May be the original torque speed characteristics was like this, so, this the natural torque speed characteristics. Now, if I try to vary the flux I am going to have probably one of them somewhat like this the next one some of like this, the next one may be like this and so on so are you getting my point. So, we are having variation in the no load speed itself and even the rate at which the speed is decreasing that is also changing so they are not parallel to each other. So we will not have the characteristic also, the characteristics will not be parallel to each other so,

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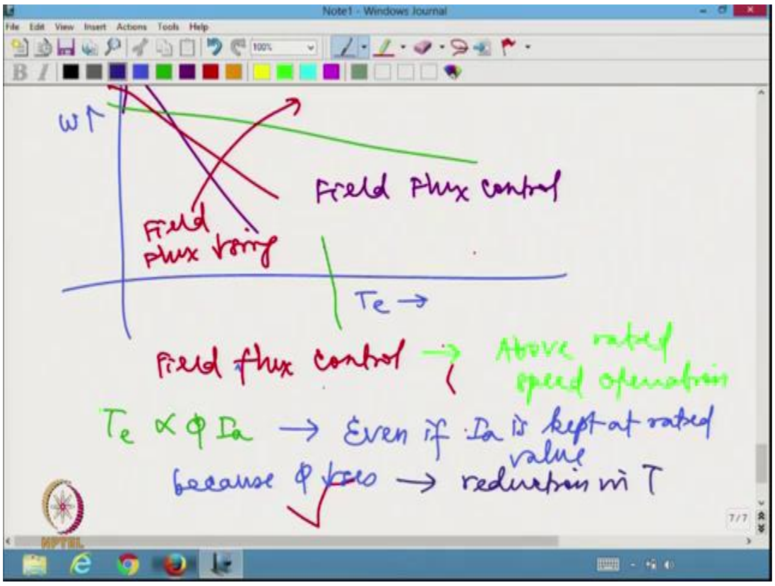

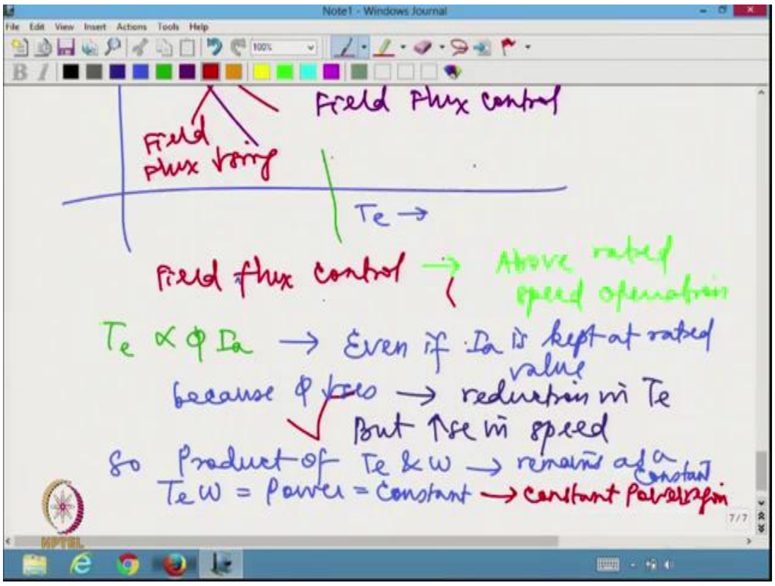

I would say if I have to show the characteristics, basically I should show it as though, this is omega this is the torque and the natural characteristics are somewhat like this. Now, for some other reduction in the field I am going to have somewhat like this another reduction in the field I may have another characteristic like this and so on. So, I will have basically the characteristics somewhat like this, for the field flux control; and if I look at it this field flux decreasing direction. So, I decrease it I am going to get more and more speed, so very clearly, field flux control is used for above rated speed operation.

So, distinctly please analyze the dynamics on your own and then come to a reasoning as to why you will have initially some oscillations before it settles down to a speed which is higher than the original speed. When we reduce speed flux we can say T_e is proportional to flux into

I_a. So, I can say even if I_a is kept at rated value, because flux decreases I am going to have reduction in T_e. So, please note reduction in Te plus, but increase in speed so product of T_e and ω remains as a constant, so, we call this as $T_e \times \omega$, which is power which is a constant. So, we call this region as constant power region.

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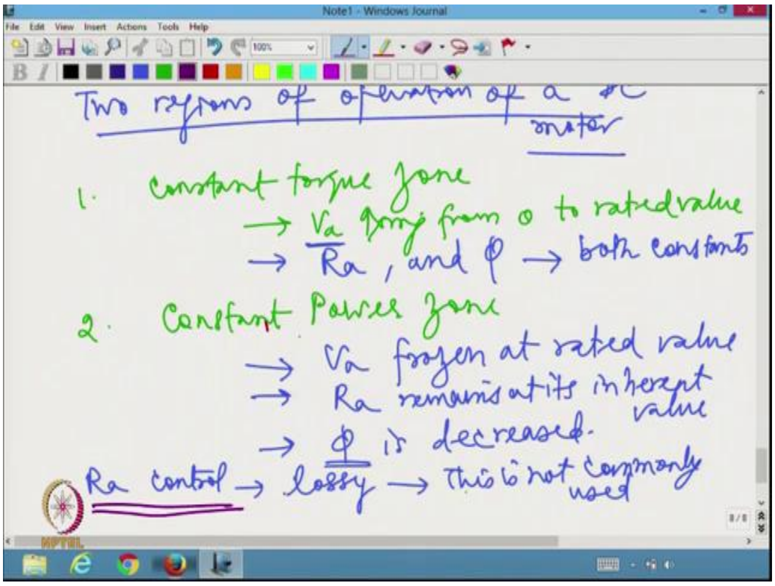

So, I can say there are distinctly two regions of operation of a DC motor. One is constant torque zone in this case we are going to have V_a increasing from zero to rated value but I will have R_a and flux both are constant. So, I am going to maintain constant torque capability of the machine under this condition the second region is constant power zone. In this case I am going to have actually V_a frozen at rated value, it is not good to increase V_a beyond rated value because the insulation are designed for a particular value of voltage. So, you cannot really expect the voltage to be frozen beyond whatever is the rated value still it is not it will not remain safe for the machine.

Machine insulation will get rupture, so, we will freeze V_a at rated value R_a remains at its inherent value but flux is decreased so we are taking about only V_a variation and we are talking about flux variation R_a control is very lossy. So, this is not commonly used this is used only when you want to demonstrate that R_a control can work well for lower speed of operation that is about it. So, I would say that although we for sake of completeness we discussed R_a control R_a control is really not a recommended one because it is lossy.

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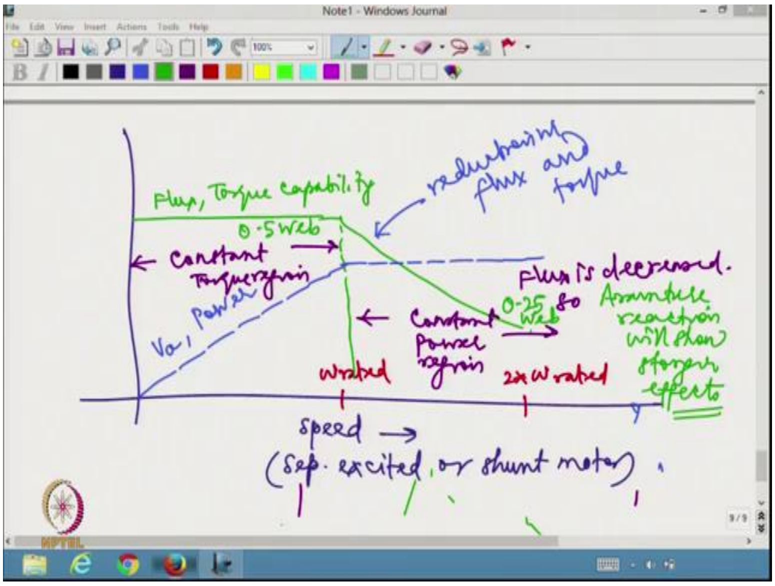

So, let me draw the speed variation in a separately excited or shunt motor drive may be this is my rated speed may be this is two times omega rated. So, if I actually look at the flux the flux is going to remain as a constant until omega rated but after that I may reduce the flux the flux may get decreased.

So, this is flux as well as torque capability. So, multiple variable we are drawing if I look at the voltage the voltage will rise like this, because as the speed rises I am going to increase the voltage. So, this is V_a along with this I can plot power also so the power will also rise slowly, because it is torque multiplied by ω. Now, the power will almost remain as a constant here the voltage will also remain as a constant but this will be the reduction in flux and torque both are specified with the help of this, so, I would say this region is constant torque region and this region is constant power region. So, at this point flux is decreased so armature reaction will show stronger effects, so, you may see that the torque actually decreases more than what we anticipated to decrease because armature reaction is going to decrease the flux further and further as it is.

Let us say, this is100 percent flux, may be some point five weber, at this point it will be 0.25 weber, so, very clearly compared to .5 weber may be armature reaction was having a reduction of 0.1 weber it would have become 0.4 weber here, but here it will become 015, so, 0.15 becomes extremely small because of which it may not be able to develop enough torque at the end of this.

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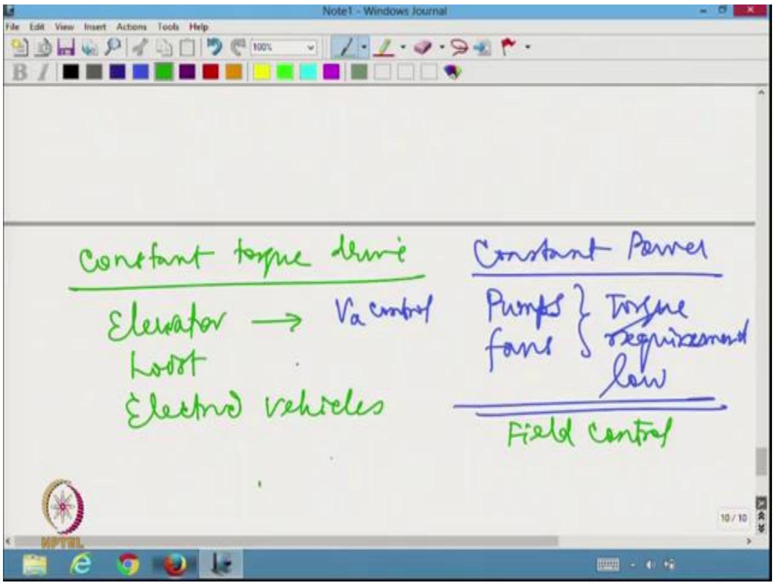

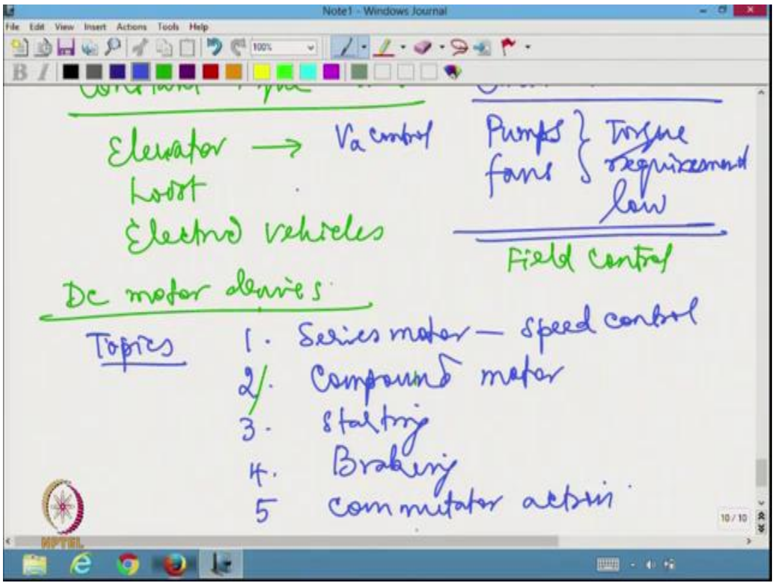

So, let us try to see what we, do you know corresponding to constant power and constant torque zone. So, constant torque zone will be employed or constant torque kind of drive will be employed in certain applications like elevator where may be so many people get in and I cannot ask them to get out if I want to adjust its speed I have to make sure that torque capability is a constant hoist, electric vehicles, these are extremely important in terms of constant torque zone whereas I am going to have in constant power zone if I try to look constant power zone for example some of the pumps, fans and so on they do not require such a large value of torque the torque requirement is low.

So, I might like to go for you know constant power kind of drive, So, here field control may be used whereas here armature control will be used so V_a control is used in this case whereas I am going to have armature control field control used in this case. So, these are the two major things as far as the armature control and field controls are there we have a few more topics to be discussed in the DC motor drive.

I will start on that today the second one that we need to look at is compound motor how the characteristics are, so, series motor actually we will have to do speed control also speed control aspects also we will have to discuss then the third one we need to discuss is starting of a DC motor drive and the forth one we might have to discuss is braking in fact commutator, still we have not discussed the commutator action also we need to discuss. So, we will just to try take a look quickly at the series motor.

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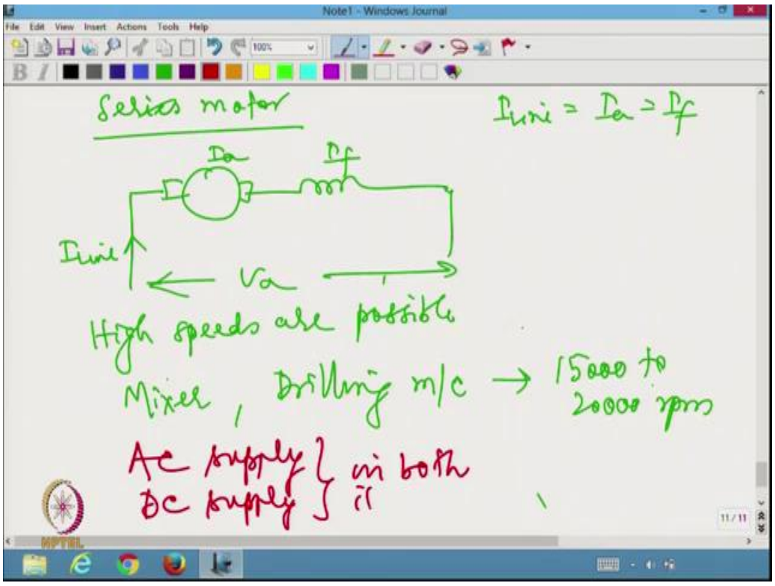

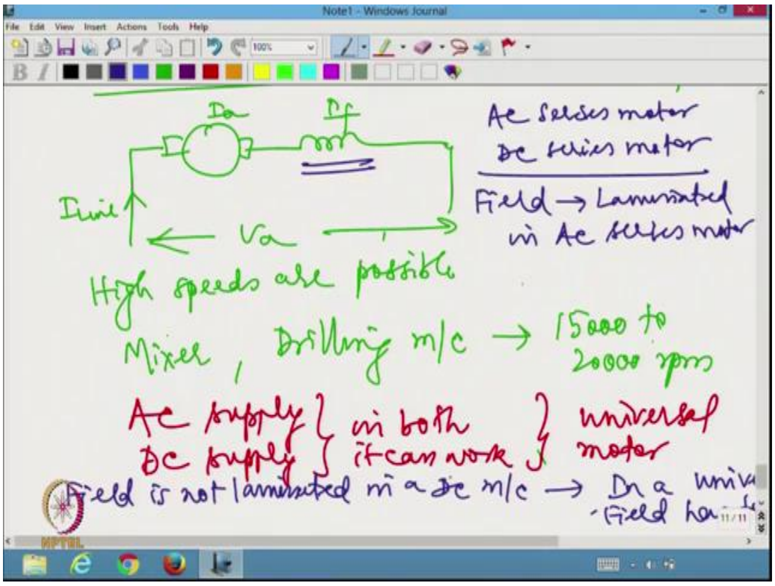

In the series motor, the field is going to be in series. So I am going to have armature here, and the field is in series and I am going to apply a supply here. So, if I write it as I_{line} the same thing is true with respect to I_a the same thing is also I_f. I will have $I_{line} = I_a = I_f$. Series motor the major advantage you will have extremely high speed possible.

So, they are actually used in an application specifically which is at home mixer and a drilling machines both use generally series motor which work at about fifteen thousand to twenty thousand rpm but at home what we have is AC supply there is no DC supply so when a motor series motor can work on both AC as well as DC supply in both, if it can work then we call that as universal motor. When we started the topic of DC machine itself we said normally field is not laminated in a DC motor in a DC machine but in a universal motor we need to necessarily.

Field has to be laminated; because you are applying AC the flux will be alternating because the flux is alternating. We definitely need to make sure that the field is also the field system also has to be laminated, so, the major difference between AC series motor and DC series motor. The difference is the field being laminated. So, field will be laminated in AC whereas that is not laminated in DC series motor.

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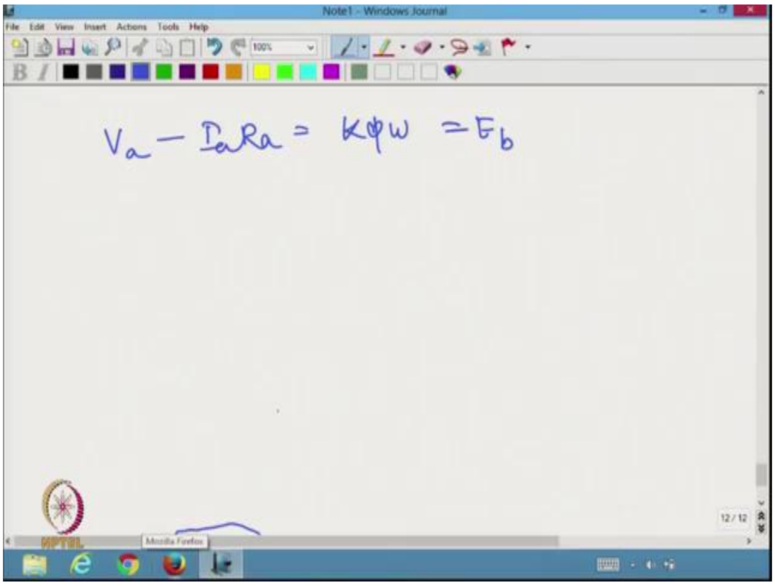

So, if I look at the series motor the same equations will be valid V_a minus I_a into R_a equal to K phi omega or E_b from which I should be able to derive the speed torque relationship for this. So, already the time is up so we will probably continue with this in the next class.