Electrical Machines
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Lecture 26: DC Machine: Starting and Braking

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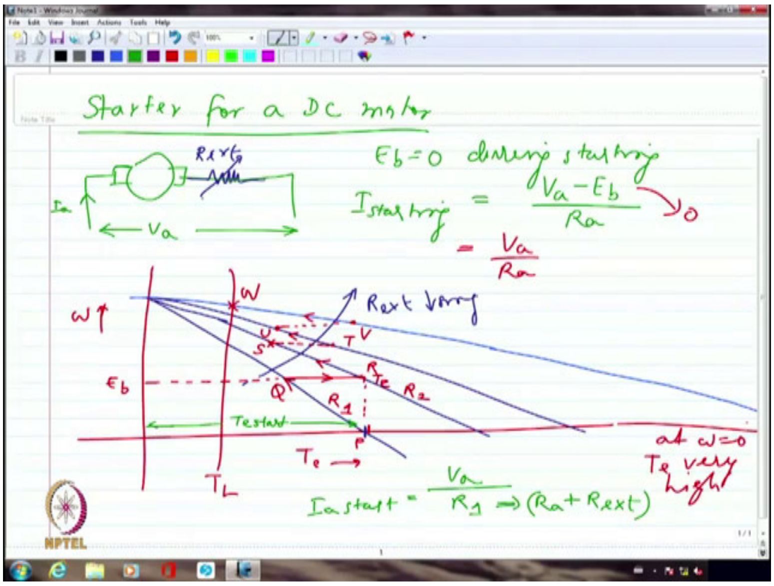

We had looked at the starter for a DC motor. We just actually started off with this discussion in the last class, we said that when we are actually applying full voltage whether it is a weekly excited DC motors or series motor or shunt motor either way if we are applying full voltage to a DC motor when the speed is 0, I am going to have essentially back EMF equal to 0. So, if this is being applied as the V_a and if you say this is I_a, I am going to have actually the back EMF as 0 ($E_b = 0$) during starting. So, if I try to look at what is the starting current, we said basically that it is going to be $I_{a\,starting} = \frac{V_a - E_b}{R_a}$, but E_b= 0.

So, because of which we are going to get $I_{a\,starting} = \frac{V_a}{R_a}$ and it is going to be extremely large and that is what we indicated if you may recall in the last class by actually the speed torque characteristic what we drew, if we normally draw the speed torque characteristic, we will draw it like this, if I extend it until it intersects the speed axis that corresponds to the amount of current it draws or the amount of torque that is developed.

So, I am going to have essentially by just extend this further it will probably intersect beyond the board further and then we are going to have actually the electromagnetic torque that is developed, is going to be enormously high at speed equal to 0, that torque will be somewhere here further. So, the torque is going to be very high if I do not include any external resistance. So that is the reason why we want to include some resistance which will actually reduce the amount of current. So, from this particular characteristics, I can show probably one of these characteristics which is with the larger value of resistance, then as I vary the resistance further and further, I am going to have essentially the characteristic somewhat like this.

So, I can say this is R external (R_{ext}) decreasing if I am going to include an R_{ext} here. So, if we start off with a large R_{ext} value, the torque is going to be this and slowly the speed is going to travel or the back EMF is going to build up because the speed is actually building up. So, I am going to have the back EMF probably coming to this value if I decide to switch the resistance from let us say this was R1 I want to switch it to R2, so at this point I am going to see that suddenly the characteristics is going to shift from let us say it started with point P, this was point Q from point Q it is shifting the point R then I change the resistance.

So, you are going to have the operating point shifting from Q to R and again, this is going to traverse this particular characteristic assuming that the load torque is not as high as what we had developed earlier. So, this is what is actually the electromagnetic torque developed, the electromagnetic torque developed happens to be higher than the load torque still there will be acceleration. So, it is going to accelerate and maybe it will reach some point here, it depends upon at what point I am trying to switch from the original value of resistance to the new value of resistance or I cut off the resistance.

So, from here say from R it has reached S from S, actually if I cut off the resistance at this point it will actually go to the point T and from T again, it will start traveling further and further towards higher speed provided I have again the load torque to be smaller and maybe at this point where it has reached U, from U I am going to again switch over to this regular characteristics with no external resistance at all.

From R to F, I would essentially go because of the acceleration inherently taking place, the motor will go because T_e in all probability in that case if it is greater than T_L, only then acceleration will take place, but it is not greater than T_L it will not take place. So, I will have basically from U again it might just go to point V and it will traverse this characteristic also and if I say that this is my load torque probably then finally is going to settle at this point as the operating point.

W will be the final operating point after all the acceleration is done with different values of resistances. So, in the process, we have never exceeded maybe whatever was our initial current, the initial current corresponded to this particular value because assuming that the flux is a constant this is an indication of what is the torque developed, but that is also an indication of what is the armature current that had flown under the initial conditions and initial condition the armature current would have been if I say, this is $I_{a\ start}$ which is corresponding to T_{start} that is going to be $I_{a\,start} = \frac{V_a}{R_1}$ where $R_1 = R_a + R_{ext}$ whatever I have included in the armature circuit.

$$\frac{V_a}{R_a + R_{ext}} = I_{a\,start}$$

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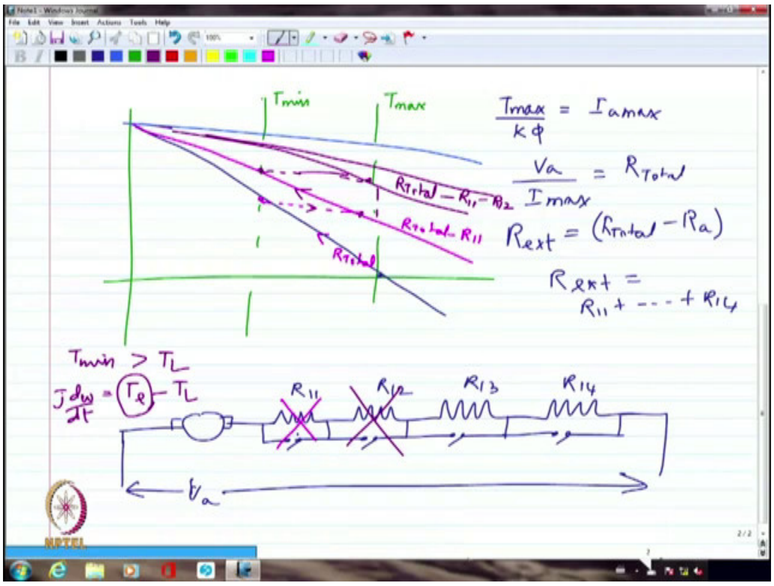

So, I can design rather a starter such that I would probably have the minimum and maximum values of torque pre-decided maybe I know what is the kind of load that is coming up on my DC motor. So, for which I have to make sure that the maximum torque that is actually generated maybe, twice or three times whatever is the load torque, so that enough acceleration comes. So, what I need to do is maybe fix up two limits, one will be $T_{\max}$ one will be $T_{\min}$.

These two are in my hands, I can decide based on the load condition, so the load condition is going to be even less than $T_{\min}$, then I am assured to have an acceleration even when I am at

$T_{\min}$. Let us say originally, I had had the characteristics somewhat like this, I do not want to exceed $T_{\max}$. So, what I need to do is to include certain resistance in such a way that I have this as the intersection point, even at the beginning of the starting of the motor drive. So, I am going to have this at $T_{\max}$ at So, I can definitely calculate $\frac{T_{\max}}{K\phi} = I_{a\max}$.

So, depending upon how much of current my DC motor can handle, how much of current the commutator can handle, I would probably decide this Ia max and accordingly I will decide what is the resistance to be included. $\frac{V_a}{I_{\max}} = R_{Total}$ will give me what is the resistance to be included. So, $R_{ext} = R_{Total} - R_a$ is the external resistance to be included.

So, I can decide how much of external resistance I need to include in my starter circuit. So, you are going to have this as the R_{ext} value. So, I may choose to include this R_{ext} maybe with four or five steps, rather than including in one step, I may just try to include let us say this is R_{11}, R_{12}, R_{13}, R_{14}. So, I am going to have $R_{ext} = R_{11} + \cdots + R_{14}$. This is what I am going to include and across each of these I may have a switch which I would close as soon as probably I reach $T_{\min}$ value because I do not want to go beneath the $T_{\min}$ value. So, I am going to have switches right across each of these and I am including this as my V_a.

Now as soon as the machine accelerate and it comes to this point where it corresponds to $T_{\min}$, I will switch on the switch, so one of the resistances will be cut off. If one of the resistances is cut off what is available is only $R_{12} + R_{13} + R_{14}$ which means the characteristic might switch to something like this. So, this is with all the resistances whereas this is going to be $R_{Total} - R_{11}$ alone and now what is going to happen is probably from here I have migrated to this operating point and then it will just move along this and it has reach again $T_{\min}$, at this point I would like to again switch the resistance maybe I would cut off this resistance.

So, this will correspond to $R_{Total} - R_{11} - R_{12}$, this pink line corresponds to when I cut off this resistance, when one of the resistances is cut off you are reducing the overall armature resistance visualized by the motor drive itself. So, you are going to have the droop definitely decreased previously the droop was quite high now the droop will come down because $I_a R_a$ drop itself is coming down.

Student: How do we choose various steps of resistance value?

Professor: Only thing is the way I choose R_{11}, R_{12}, R_{13} and so on I should make sure that it does not supersede or exceed T_{max}. So, I would rather chose for the entire starter design is hovering around basically to make sure that I always keep my two torque point the maximum and minimum within specified limits, every time I cut off when I cut off it is actually moving from here to here, it is well within $T_{\max}$ in this particular case, but in the other case it is exactly probably going close to $T_{\max}$.

In the next case again, I may have one more which will again come closer to $T_{\max}$, but I have to make sure that every resistance is designed in such a way that every step they need not be equal, nobody said R_{11} R_{12} or R_{13} they all have to be equal, not at all. So, I will design each step of the resistant in such a way that I am going to get, the maximum value of torque within the safe limit that is $T_{\max}$ and similarly the minimum value of torque as $T_{\min}$, which is good enough to accelerate the motor, otherwise I will not see any acceleration.

Student: How do we decide $T_{\min}$?

Professor: $T_{\min}$ is, it has to at least provide some amount of acceleration. So, which means $T_{\min}$ necessarily has to be greater than T_L, if it is not greater than T_L I will not get $T_e - T_L = J\dfrac{d\omega}{dt}$, this is what is the mechanical equation we wrote $T_{\min}$ also corresponds to the electromagnetic torque. So, unless I have that exceeding T_L I will not have any accelerations. So, it will not be able to accelerate at all until even from $T_{\max}$ to $T_{\min}$ have shown some accelerations that is only because I am still having some excess amount of torque as compared to load torque. $T_{\min}$ depends upon the load, absolutely or I can say if I know what is the load torque and I kind of know how many steps of resistance I want to include I will be able to design $T_{\min}$ based on that as well. I can do it either way.

Student: How $T_{\max}$ is decided for a particular motor?

Professor: I decide my $T_{\max}$ depending upon what is the value of the current my motor can withstand.

So, the manufacturers data will tell me the average current or the steady current can be 10 amperes, but for a short while you can probably pass 20 amperes. That short while they will decide they will probably tell you 20 millisecond, 40 milli second, 1 second, whatever. So, I should know the inertia of my load as well completely. Only then I can say how long will it take for the back EMF to build up.

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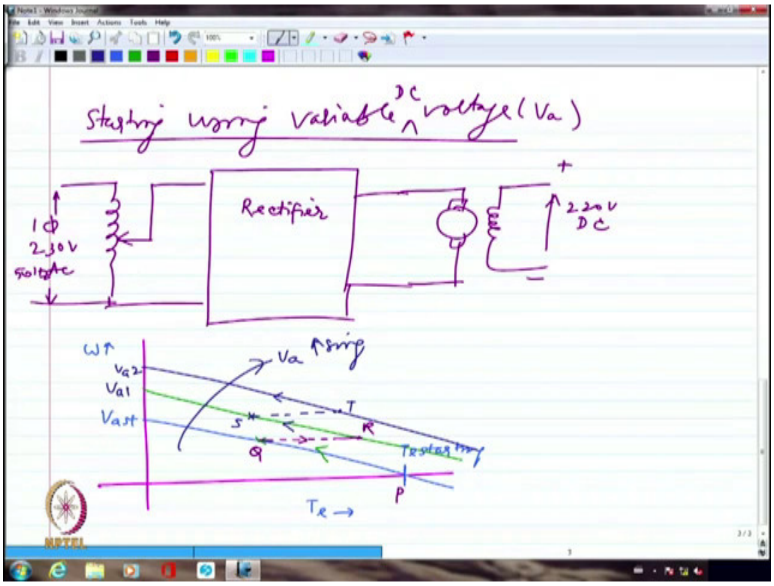

So, apart from this I can also try to do starting using variable DC voltage V_a. So, if I have a variac and if I have a diode rectifier, I should be able to modify the voltage that I am applying to the armature circuit slowly and then as the speed builds up automatically the current would fall then I can increase the armature voltage itself. I can do that if it is a separately excited DC motor drive or if it is a shunt motor drive also if I am operating it as a separately excited DC motor drive with the separate supply for the field only under that condition this is possible, this we use very commonly in our laboratory, what we try to do is to provide a variac.

So, let us say this is the single-phase supply from which I am going to pass it through the variac so this is single phase 230 volt AC supply, which actually goes to the rectifier. So, I am not showing the rectifier explicitly the circuit here it can be a diode rectifier, simple diode bridge rectifier. So, the rectifier output actually is going to the DC motor drive. So, this is going to be my DC motor drive and of course field separately given to the DC supply. So, here I may apply to 220 volts DC directly.

So, under this condition, I can initially start off with very very small amount of voltage. So, let us say this is my characteristics that I am trying to draw. So, let us say this is going to be the voltage that I apply and this is the maximum current that can be withstood by the DC motor because the torque and current indirectly are related to each other, proportionally related to each other, so I can say this is T_e and this happens to be my T_e starting and this corresponds to V_a starting, whatever I give as the V_a starting.

Now I am going to increase the voltage once the speed builds up, so because of the current flowing there is going to be torque, the torque is going to accelerate the motor drive and once the motor drive accelerates to probably certain speed, I might like to increase actually the voltage to another value. So, I have just shown one more voltage characteristic with the different armature voltage. So, from here it is going to shift to this point. So, the first point was P, this is Q from Q it is shifting to R.

Again this will get accelerated like this, may be once it reaches again some point S, I am going to switch to another voltage, so from here, it will go to another point, which is probably T. So, from here again, it is going to accelerate and so on and so forth. So, ultimately, I do this until full 230 volts is applied, if the rectifier is going to give me the rated voltage of the DC motor when full voltage is applied to it. So, this is the variables voltage starting. So, this is going to be the V_a increasing direction.

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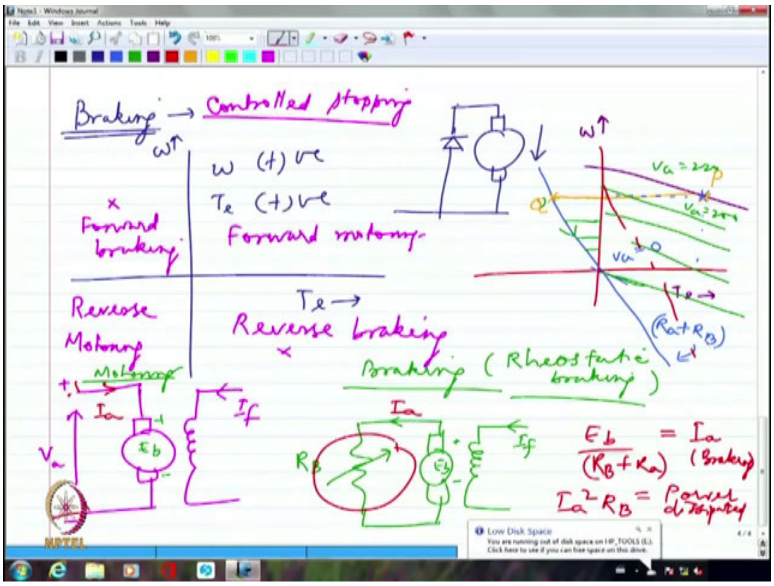

The last topic I would like to cover before I go on to commutation is braking, I will just give you a glimpse of braking, I am not going into the details of braking, what is braking?

Stopping the machine, you cut off the supply it will stop, what is the problem? Why should you have some kind of braking method?

Student: Because of the back emf.

Professor: Let the back emf be there, how does it matter?

Student: Sparking?

Professor: No, why would it spark?

Student: Due to inductive current.

Professor: Okay, so you put a diode, diode will take care of the current, what I mean is, see he is saying which is a valid point if it is an inductive current if this is a DC motor drive, if I cut off the supply completely the current had been flowing in this direction then immediately what will happen you are trying to interrupt an inductive current that is going to be causing huge amount of sparking if you try to cut off inductive current. So, if you are going to have actually the current flowing through the DC motor drive, which is inductive because La is there. So, if I cut it off then immediately I am going to see huge amount of $L\frac{di}{dt}$, because the current even if it was one or two amperes, let us say the motor was on no load still I am going to have the current interacted with in no time.

So, $\frac{di}{dt}$, dt become literally 0 because of which I have huge amount of voltage induced. So, if I put a diode let us say the diode should get forward bias, because of the inductance stored energy. So, it will essentially allow a path for the current. Why do you really require brake. Let us say I have elevator I have gotten into it. I am at the top floor and I want to come down.

I will switch on the supply, I do not have any control, what do you think will happen not me alone, maybe 10 of us, huge weight okay. What do you think will happen? It will move, very much move why not? Gravity will pull it, Will it not? Will the gravity not pull it? If I switch ON definitely I am going to have whether I switch ON or not in fact it will start moving, are you getting my point, because gravity will essentially pull it down and it will come and crash basically on the floor and every time I am trying to come down this will happen, in the opposite direction which will oppose the motion of that particular cage in which we are all standing downward, if it would oppose then I would have a controlled movement.

So, whenever we want a controlled movement whether in the positive direction or in the negative direction, but with the torque opposing the direction of movement that is what is known as braking, the torque and speed aid each other we call it as motoring, the torque and speed oppose each other we call it as braking. When the torque and speed are in the opposite directions of each other please remember when we drew actually the torque speed characteristic, we always showed torque was also positive and speed was also positive. So, both were aiding each other whereas if I have torque to be positive but speed to be negative or if I have torque to be negative and the speed to be positive that process is generally braking.

So whenever I develop a torque which will oppose the movement, that can specifically happen only in active loads because friction anyway will always oppose the moment, frictional torque is considered to be a load torque all the time because it will always oppose the movement, whereas gravity I cannot say that that is why gravitational loads are generally known as active loads, they can work in either direction, they can either aid the movement or oppose the movement.

So, if you are looking at a load, for example a vehicle is going down the gradient, in that case again, unless you put a brake it will just go in extremely large speed because gravity aids the motion. So, you would like to rather apply brake not to waste the fuel, but to have a control over the movement, right. So, braking becomes extremely important under certain conditions where I would like to have a controlled movement because I might like to prevent an accident. I make like to give some user comfort or I might like to probably specifically stop at the point.

So, let us say I am going by metro train he cannot simply switch off the supply and say wherever it wants to, let it stop. It has to stop exactly in front of the platform, we cannot jump into the car basically, so we have to make sure that the user comfort and control is taken care of. So, braking basically is controlled stopping. So, in many situations, we will require controlled stopping. So, control stopping will involve always the speed being opposed by the torque.

So, if I am going to have positive speed, I might have maybe negative torque, similarly if I have negative speed, I am going to have positive torque. So, these two quadrants are generally meant for in the speed torque plane they are meant for braking. So, I would say this is generally forward motoring, this is reverse motoring, and this is going to be forward braking and this is reverse braking. So, these are the four quadrants of operation in speed torque plane.

We talk mainly about forward motoring after all if I give the supply in the opposite direction not the field supply also one of them only should be given in the opposite direction in that case, I will see essentially reverse motoring because I_a multiplied by I_f is torque. So, if I am going to actually reverse let us say only the armature current then the torque that I generate will be in the reverse direction. So, obviously this will also start accelerating in the reverse direction. So, it will be essentially reverse motoring.

So, one of the methods of braking normally what we employ for a DC motor, let us say this is the normal motoring operation, here is the field and this is the armature supply with plus here and minus here. So, this is the normal motoring operation, what we will do for braking which we call this as rheostatic braking because we are going to include a rheostat in the armature circuit removing the power supply itself. So, we are going to have essentially the same armature here and then I am going to include a resistance which is the variable resistance. So, this is the braking resistance that I am including across the armature.

So, if I have this, whereas the field is very much ON, let us say I am going to have the field still ON. What is going to happen? There was a back EMF already. So that back EMF would still exist because the mechanical time constant of the drive will be generally larger as compared to the electrical time constant. So, I am going to have the speed continuing to exist whether I like it or not it will continue to rotate in the same direction because of the kinetic energy stored. So, what is going to happen is, this will start passing a current in this direction. So, this will be the I_a direction whereas here the I_a direction was this please note that I_a direction has reversed.

If I_a direction has reversed, I am definitely going to have the torque also reversed. So, I am going to have $\frac{E_b}{R_B + R_a} = I_a \text{ (braking)}$.

Student: Is any power supply connected during braking?

Professor: No power supply is given during braking, already E_b was there. E_b was there because of the field current and the speed, the field current still you are having if it is a separately excited DC motor you would continue to give the field supply.

Student: How do we disconnect the power supply?

Professor: Basically, you will have a switch, open the switch. So, you cut off the switch and then include a resistance. So, for the braking you need to open out the power supply and then only connect a resistance. So, this is going to create essentially an armature current in the opposite direction but please note that it is going to dissipate the power in this resistance that is going to be $I_a^2 R_B = \text{Power dissipated}$. I am not utilizing the power very effectively, but I am making sure that the power dissipated is at the particular rate, if it is at a particular rate decided by what is the R_B value. So, I can choose R_B value according to whatever is my requirement. So, I would be able to dissipate this power and because of which the kinetic energy will get depleted eventually.

So, we are looking at basically having a control stopping process although we are not utilizing this electrical energy effectively. If it is a cold country or we are talking about Delhi kind of winter, we can probably use this for heating up the car if it is an electric vehicle. So, this is one of the methods of braking let me show the characteristics also for this. If this had been the original characteristics of the DC motor, let us say this is ω and this is T_e. This is the original characteristics of the DC motor, maybe originally, I was operating at this point, this was the point at which my machine was operating. So that corresponds to certain value of T_e and certain value of speed.

Now what I am trying to do is to include a very very large armature resistance and also cut off the power supply if I had cut off the power supply my V_a should be 0, So, I should have the characteristics actually starting from the 0 point but I have included a huge amount of resistance. So, maybe I should show it as though it is highly drooping with V_a equal to 0 because I have made the armature circuit voltage equal to 0. I have not included any armature circuit voltage as I decrease the voltage I was showing parallel lines which were coming beneath one another, now I have come down to V_a equal to 0 because I have got V_a equal to 0 this will be the point corresponding to R_a+R_B, both resistances are included in the circuit and V_a is also 0. So, this is the characteristics corresponding to this particular condition of operation.

So, from this point the speed would not decrease abruptly so the speed will essentially remain almost the same. So, originally the operating point was P, now it will shift over to Q. From P it will shift over to Q, please note in Q the speed is still positive, but the torque is negative because you are having the armature current in the opposite direction. So, we are going to have now this particular operation will traverse this particular trajectory. So, it will try to come down to 0 eventually.

So, we are going to have switching over of the characteristics from P to Q if I want as I see I come down in my speed the torque is decreasing the negative torque is decreasing, if I want a good amount of torque, I might have to adjust the resistance value.

Student: what are those lines on the torque speed characteristics?

Professor: This line is basically similar to my speed torque characteristic, this would have been at V_a less than the original value, this would have been another one there should have been another one, this will be the last one which is correspond to V_a equal to 0, currently I am looking at V_a equal to 0, if I increase the resistance what will happen the droop will increase.

So, if I had plotted this is V_a equal to 220, this is V_a equal to 200 with V_a equal to 200 and a larger resistance I would have had the characteristic somewhat like this, right it would have come down. So, that is what I have done basically, I have essentially drawn the characteristic corresponding to the larger armature resistance with V_a equal to 0, and the same thing has been extended into the other quadrant because I am already looking at a speed which is a non-zero value, it is not at 0 speed is already at a particular value. So, I am not discussing any more methods of braking, this is one of the methods of braking which is commonly employed to have a good control over the stopping of the motor drive. Although it is not energy efficient, it is not really allowing you to save energy, it is only dissipating the energy in the resistance.

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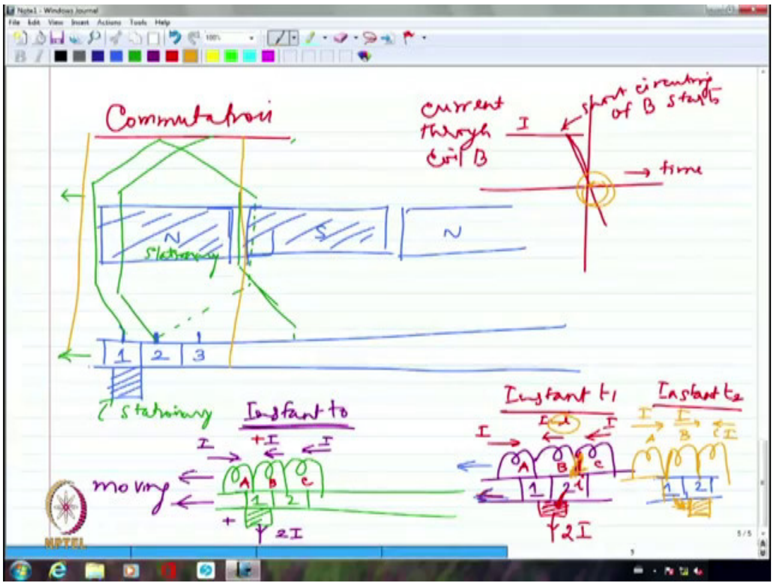

In the last topic I would like to take up is commutation, I hope you guys remember the windings we drew. I am just going to recall that very little bit. So, what we drew as the lap winding work it started off like this, it went to the next pole back side of the conductor then it came to the next slot and so on and so forth, this is how it was. The windings were drawn like this if you may recall in a lap winding and we normally drew, maybe so many slots for north pole. So, this is let us say north pole, north pole ends here, and south pole is probably going to start from here something like this. This is south pole, again I am going to have a north pole whatever, so I am going to have the pole somewhat like this.

Please note that this is the portion I am shading this is north pole, this is south pole and so on. Now we told also that the brushes are inserted actually for every pole one brush will be inserted if I am talking about the lap finding for every pole I will have one brush. So, let us say from this junction I am having one commutator segment from here I am having another commutator segment and so on and so forth. So, maybe I have one commutator segment second commutator segment third and so on this is at the cusp of the North Pole and the other South Pole, So, I will probably have one brush inserted here and depending upon how many poles I had, I will have essentially the number of poles will be the dividing factor for the total number of slots and then I will insert probably corresponding to the N+1 slot I will eventually include one more brush and so on and so forth.

Let me first of all concentrate on this brush I want you guys to understand that the winding is moving along with that the commutator segment is also moving and I am looking at this to be stationary, right, and this should also be stationary, brush is also stationary. So, the brush is always inserted into a winding which is at the cusp or border between a North Pole and South

Pole or South Pole and North Pole and so on, please understand that the brush is stationary so also are the poles.

So, the brush is with regard to the pole it will always be in the interpole region between North Pole and South Pole or South Pole and North Pole and that is how it is going to be. The brush is stationary and the brush is corresponding to the winding which is coming along the cusp. So, similarly, if there is a winding coming along here you can see this is also coming along the cusp almost at the end it is being inserted. So, similarly whatever is the winding that would have come along this maybe it would have come like this and then here one more brush will be inserted and so on, that is how it is.

Now I can just represent this as though rather than showing the diagram like this, I can just show 1 here 2 here and I can show a brush here. Maybe there is one more commutator segment here. So, I am going to have maybe one winding like this, one more winding like this and one more winding like this. This is how it goes. I am just showing the winding in a compressed form rather than showing the entire length and so on and so forth. So, this is how the windings are represented. So, this shows actually this entire thing going around and things like that. So, if I look at one, I have one winding going around like this which is ending up in 2 so that is what I am showing from 1 winding goes and goes into 2 similarly from 2,1 more winding goes into 3, and so on and so forth.

If I say that this is the positive brush, if I say that this is going to be a positive brush, the current will be coming out of this if it is a generator. So, may be, I am going to have the current flowing like this here, which maybe I, similarly the current will be flowing like this in series the same current flows here. Please understand because nothing is collecting the current from 2 so whatever is the current that is flowing in this coil will also flow into this. So, this is going to be I as well. So, what is coming out here will be 2I, may be I am showing two parallel paths. So, totally what I am getting is 2I conductor current is I and the current that is coming out of the brushes is 2I.

These are not stationary you are going to have this also moving and this also moving. Whereas the poles are stationary the brushes are stationary. So, let us say this is our instant t_0 when I have $t_0 + \delta t$ or slightly that is a time you know, that is elapsed. Then I'm going to have the same commutator segments. Maybe I am going to have this as 1 this is 2 and I am going to have the same coil because the coils and the commutator segments are moving together. Let me name this maybe this is A this is B this is C. Now I should say this is again A this is B this is C and I am going to have actually the brush probably slightly moving away, It looks as though the brush has moved away but actually the commutator segment has moved away the brush is stationary but the commutator segment has moved away.

Originally B was carrying the current entire current I which was being collected by the brush. Now the brush is actually making contact with two commutator segments 1 as well as 2 and if you look at it coil B is connected between 1 and 2. So, it is as though coil B is short circuited because of the brush is actually short circuiting the commutator segment 1 and 2 between which coil B is connected. So, coil B is going to be short circuited whether I like it or not because normally the commutator segments widths are somewhat larger and the brush is not going to be as large but still it is larger than the mica, the mica is really thin in between and the two sides of the copper generally are bigger and I am going to see that at a time this brush is going to short circuit 1 and 2.

Now what is going to happen is coil B is under confusion, because coil B is short-circuited and part of it is going to be showing affiliation to coil A and part of it is going to show affiliation to coil B. What will happen is some current will be collected here directly from commutator segment 2 which means coil B and coil C junction is actually pushing some current into the commutator segment 2 which is actually being pushed into the brush. So, if I call that current has some I, what is going to happen is if this had been I some portion of small I has gone into here. So, this current is going to be I-I, Kirchhoff's current law.

Whereas this current is still I, so the total current that is carried by the brush is still I+I-i+i so it is 2I still that is not going to change but the problem with this coil is it is not very sure whether it is carrying the current in one direction or the other, that is the problem. So, I am going to see that this is going to be 2I.

At some point maybe the brush will make equal amount of contact with 1 and 2, both of them at which point it will actually see that it is collecting this I = I itself. Because of which you will find that coil B is carrying literally 0 current, if i = I eventually what is going to happen depending upon the area of contact between the brush and the commutator segments if commutator segment 1 and commutator segments 2 both of them are making equal contact with the brush then both of them probably would be pushing the current of I. In which case I am going to have essentially B to be carrying literally 0 current.

So, please note that B was originally carrying a current of + I if I may call this direction as +I and it can slowly come down to 0. So, this is instant t_1 so I may say that originally it was carrying a current of I, slowly it will come down to 0 and then it has to go the other way around.

Now this is the point at which short-circuiting of the B starts. B is the coil we are talking about so this is with respect to time and this is the current through coil B. Please understand that because this is moving, and the brush is just stationary the brush would rather make contact with two different commutator segments at a time and depending upon the area of contact how much is the current collected that changes.

Now at instant say t_2 where almost I am going to have this moving further and further. This has moved further and further because of which I am going to have here is 1 here is 2, and I am going to have the entire brush making contact only with 2. There is no contact with 1 at all. Let me draw again the coil so I am going to have between 1 and 2 again B here is C and here is A, right. This is how it is.

Now please note that this is I that has not changed now that is no collection of current from here. So, B should carry the current in this direction. Because these two are in series there is no collection of current from 1 because of which I am going to have essentially the current carried in this direction itself whereas C would carry still the current in this direction. C would go through the same process when again 2 is short circuited with 3 and so on and so forth that is how it takes place.

Now if no shifting of neutral axis had taken place the coil had not had got inductance, the current transition would have been smooth and linear. You would see that according to the area of contact that much of current is being collected. There is no problem but if I have armature reaction, which is very much there. I told you that the neutral axis gets shifted, originally I was having the neutral axis here and here for example, the neutral axis gets shifted because of the neutral axis getting shifted I am going to have an induced EMF that is taking place in the coil, which is like coil B which is in the cusp.

So, I am going to get an induced EMF in such a way that whatever is the change in the current it is going to oppose that, right now the current is trying to go from +I to -I. Obviously, the induced EMF will oppose that. So, it is going to say that I would not allow the current to go down to 0. So, although at this point I should have seen 0 current must have been reached or whatever or it should have completely transition to +I to -I what will happen is the induced EMF is going to actually make the current go through, the commutator segment 1 as well because there is some amount of leftover current, I expected that the entire current should have been gone to minus I from plus I, maybe I still will have some amount of leftover current because coil B is not allowed to change over the current direction completely.

It actually had I-i that small i had been increasing so the small i became capital I at some point where the current became 0. After that the I is still increasing in the opposite direction. So, it would have become greater than I. So, I minus minus I plus delta I that what it should have been.

So, I would have had more and more current coming up in the opposite direction and what is going to happen is before it completely reaches the other end of the spectrum that is from +I before it reaches -I, it is going to actually the voltage that is induced because of the shift of the neutral axis is going to push the current through commutator segment 1 also because please understand this I was coming in this direction from coil B, which represented actually opposite of the current, that is you can see that this I is actually coming through this direction from coil B, from this end.

So, here also there is going to be a current which is actually going to rather shift itself through the spark or the ionization of the air which is surrounding commutator segment number 1. Before we actually switch over to induction motor, we will revisit this one and then switch over to the induction motor.