Electrical Machines
Professor G. Bhuvaneswari
Department of Electrical Engineering
Indian Institute of Technology Delhi
Lecture - 20
DC Machines – Armature Reaction

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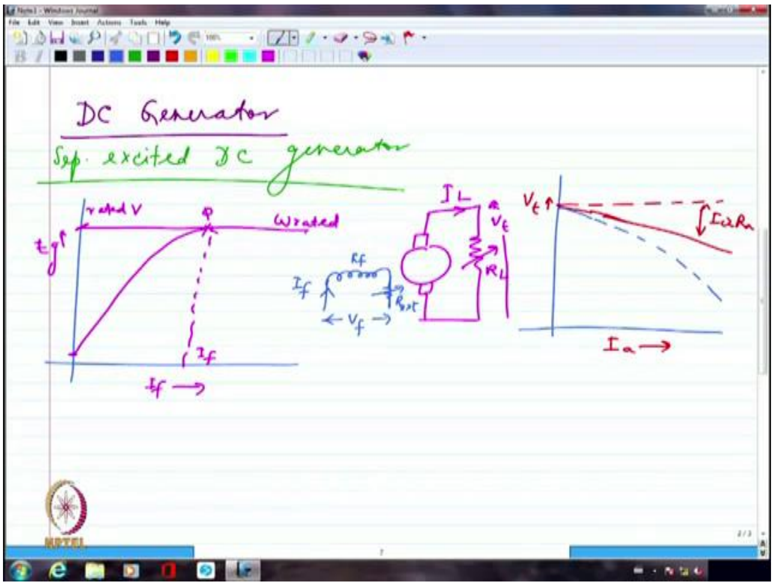

So, lets us try to take a look at now again the DC generator in that we are looking at separately excited DC generator. We looked at two characteristics, one is OCC, other one was basically the external characteristics and I had just embarked on discussing armature reaction. So, let me again redraw the OCC, so in separately excited DC generator we were actually pointing out that E_g will be having a non-zero value even with I_f equal to 0 and then we are if there is residual magnetism, of course, and then we are going to have it somewhat like this.

This is what my open circuit characteristics is and we also showed something called a load line. We were talking about basically where is the operating point for this particular case and we said that if I am going to talk about the rated field current somewhat like this, this is what will be the rated flux as well, so this will be actually my rated generated voltage.

This will be the operating point and we said that this particular thing will correspond to a speed which is corresponding to rated speed, when I am driving the generator at rated speed. So, I would say that the rated EMF or rated voltage of the machine is defined as that voltage that is obtain from your generator when you are passing rated field current through your excitation winding and then you are driving the generator at rated speed.

That is what is defined as the rated voltage of the generator, and then we were trying to look at if I am having the generator here and I am connecting a load which is a variable load, so we were looking at what is the terminal voltage of the generator and we were looking at what is the current that is flowing through the load which is same as armature current in the case of a separately excited generator.

So, I may have my field winding here some book show the field winding perpendicular to the armature winding because the brushes are always connected perpendicular to the line wherever the field lines are going generally perpendicular to that the brushes will be placed, so that is the reason why sometimes this is the kind of representation some of the book show, the field will always be shown perpendicular to the brush axis, that is how it will be shown.

So, I am going to have essentially the field current flowing like this, so I have V_f connected here, I may have a resistance connected in series to vary the field current and this is going to be my R_f inherently and this is going to be R_{ext}, the external resistance that I have connected. So, if this is going to be my external characteristic were I am drawing the variation of what is the terminal voltage with reference to the armature current that I am drawing.

If it had been an ideal generator without any drop in the form of resistance drop within the machine I should have gotten a flat characteristic, but I am not getting a flat characteristic because I am going to have definitely some amount of I_aR_a drop taking place I am showing this in an exaggerated fashion but this is my I_aR_a drop. This is essentially because of the internal drop that is taking place within the machine conductors which are manifesting a resistance of R_a.

So, this is going to be I_aR_a drop which is contributing to in one sense the regulation of the DC Generator otherwise I should have had the voltage as a constant at 220 volts or whatever, but apart from this we just introduce one more thing called armature reaction drop, which is going to be somewhat nonlinear, it will not be linear because it is playing around with saturation and other things which are basically the manifestation of any magnetic circuit involving Ferro magnetic material.

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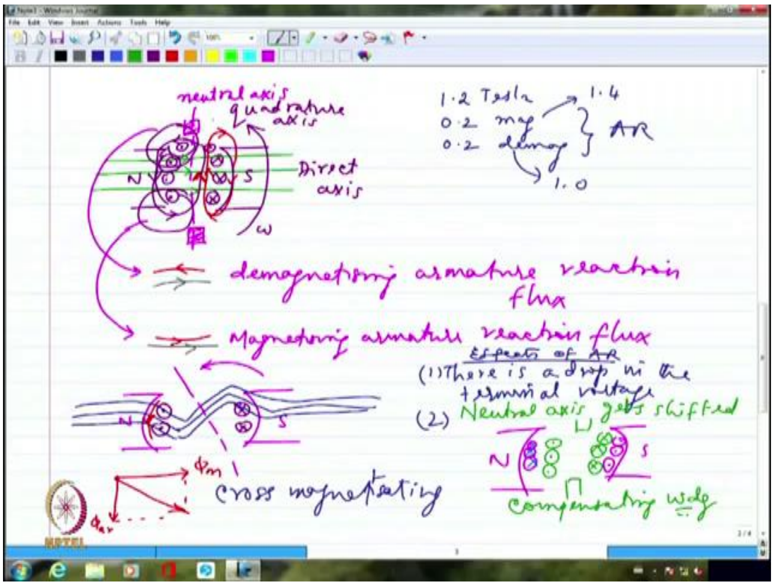

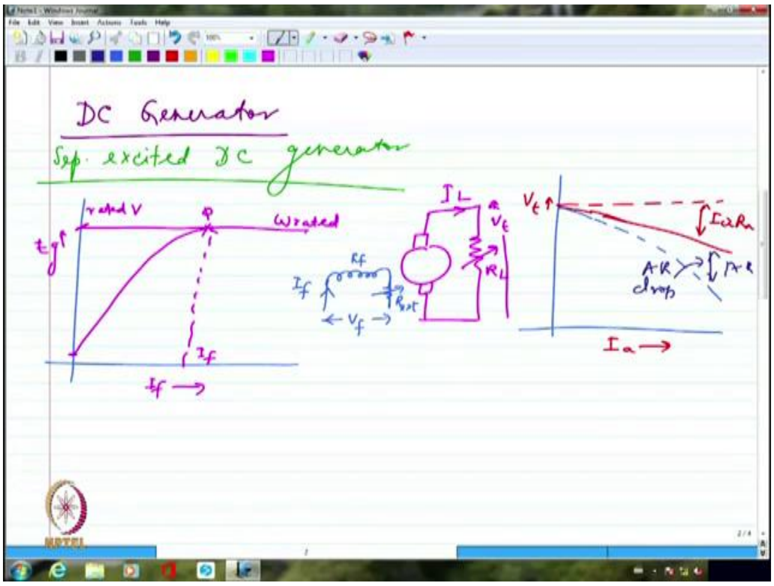

So, let us try to look at what is this armature reaction, for which let me try to first of all draw the original field how this was manifesting itself so this is north pole, this is south pole and I was having the magnetic field line going like this basically this is how the magnetic field lines are going, I am not showing the completing path of this magnetic field line which will go through the yoke, of course, it will go through the yoke.

So, this was the original field line, so my neutral axis if I try to look where the neutral was magnetically this is what was the neutral axis, and that is where we normally place the brushes, so that if we are actually making the conductors change over from dot to cross current or cross to dot current that happen exactly along the neutral axis so that it became simpler because the current is going to be really-really minimal or almost closed to 0 at that point because of which I am going to have mostly the change over from plus to minus current or minus to plus current very smoothly.

Because it is drifting from South Pole influence to North Pole influence and North Pole influence to South Pole influence. So when it is drifting obviously it will go through a 0, the current will go through 0 and when it is going through 0 it is always easier to change over so that is the reason why we are placing the brushes some were here so the brushes are normally placed along this axis which is perpendicular to the magnetic axis.

So, we called this as a neutral axis. In one sense, in many of the books they may say this as quadrature axis and we call this as the direct axis, so the direct axis is parallel to the field lines that are created by the main poles, north pole and south pole under quadrature axis is perpendicular to that which is also incidentally the neutral axis, if I am considering only the main field flux.

Now, initially may be my conductors what I have placed here are just having induce EMF, I have not connected any load and if I am assuming may be the direction of rotation is anti-clock wise direction, this is omega then maybe I will have dots verify this, and I am going to have cross here Fleming's right hand rule so you will have dots here and cross here. If this dot and cross currents became pretty much influential because I have connected probably a load in such a way that I am drawing more and more current.

Initially when I did not connect any load I was having literally zero current, when I have actually connected a load and I am drawing more and more current by reducing the resistance probably I am going to have higher and higher current. When higher and higher currents are coming, this armature conductors will also create a flux after all they are also placed in a magnetic core, ferro magnetic core.

So, they are not going to keep quite they will definitely produce a flux, until now we ignored it, but now we will have to consider so when we are considering that and what kind of reaction it is going to have on the main flux we call that as the armature reaction. So, the armature reaction is the reaction of the main field flux to the flux produced by the armature conductors which are carrying current.

Now, when it is not open circuited anymore, so if I consider this I will definitely have may be around each of them I have to draw a flux or field line, I will have multiple number of them but on the whole maybe I can draw something like this, this will be the total line of you know field line, what I will have and if it is dot I can say that this indicate the direction of the fingers, how they curve that is going to indicate the direction of the field line, so I am going to have the field line in this direction, field line in this direction, of course, they will go like this, this is how the field lines are going to be.

Similarly, I should be able to draw the field lines for this as well, I should show them more through the air gap which will actually be the other way round. This is how those thing are going to be, so I am having the field lines created by the armature conductors which are actually going to be you know here if I look at it, for example, the armature field line is like this and main field line is somewhere here like this, this I am talking about, I am talking about this portion, so I am talking about this portion which I have enlarge and I am showing it like this.

Whereas, if I look at this portion, if I am looking at this portion I can say I am having the main field flux like this and the armature flux is also like this. So, this is this portion that I am talking about which I have enlarged, are you getting my point, so at some point the main field flux is directly opposed by the armature flux at some point the main field flux adds up to the actually main the armature flux, so I would call this as magnetizing armature reaction flux where they are adding each other, I would call this as demagnetizing armature reaction flux.

There are other portions where, for example, I am having the pole here, north pole and south pole, and I am having some conductors here as well, very closed to, you know, the pole curvature itself and there I am having this dot again and this cross here and if I look at the flux line here it is actually perpendicular, it is not neither aiding nor opposing, it is actually perpendicular, so because of which if I actually look at the resultant here this is the way I am going to have my main field flux, and I am going to have my armature flux lines somewhat like this, depending upon the strength of the armature current, of course.

So, I will call this as ϕ_{main} this is $\phi_{armature}$, so when I actually look at the resultant, I will probably get the resultant somewhat like this, the resultant of the two will look somewhat like this whereas if I look inside the armature core, this is in exactly in the opposite direction, so what I am going to have as the overall flux actually will be somewhat like this, it will actually come as a straight line, it will probably bend like this somewhat and here it might probably bend in the opposite direction and again I should probably have some bend like this and then it should go like this.

So, I am going to have all the lines rather going like this all the field lines are somewhat going like this, so the armature reaction actually distorts the overall flux, at some point it is magnetizing flux, at some point it is demagnetizing flux and I will called this as cross magnetization, it is neither demagnetizing effect nor magnetizing effect, it is kind of, you know, modifying the magnitude as well as direction.

So, I call this as the cross magnetizing effect, so the armature reaction essentially create three effects on the overall flux profile at some point it is creating a magnetizing effect, so I should have actually seen an increase in the flux, but already I am operating close to saturation. So, the increase will not be as much as what I expected to be, the magnetizing flux will not be able to increase the flux, let us say I was originally operating at some 1.2 tesla flux density, may be 0.2 is the magnetizing effect and 0.2 is the demagnetizing effect as well due to armature reaction.

So, I should have had here 1.4, I should have had here one, coming down to 1.0 is very easy, no saturation effect but going up to 1.4 became very difficult, because already it is saturated to a large extent. So, instead of probably going to 1.4 it may be go to 1.25 or 1.3, nothing more than that, it may not be able to go very high. So, the overall effect that is seen is the net reduction in flux, all though magnetization and demagnetization are happening at the 2 ends of the pole, main pole you can see that this is essentially demagnetization, this is magnetization.

So, we are going to have both magnetizing effect as well as demagnetizing effect, the magnetizing effect is not as pronounced as the demagnetizing effect because of the saturation coming into picture, so the net effect is an overall reduction in the flux, if there is the overall reduction in the flux clearly there will be a drop in the voltage whether I like it or not there will be a drop in the voltage.

So, this drop in the voltage is what is manifested then I draw the external characteristic, so I would say this is actually armature reaction (AR) drop. The armature reaction drop gets more and more pronounced when I have large and larger armature current, because the effect of the armature flux is really much more influential when I am going to have larger and larger current through the armature.

That is the reason why you would see clearly may be initially, it may be somewhat linear but as it gets to larger and larger currents the saturation effect is much more pronounced because of which I am not going to see any increase in flux at all after sometime, but I would see a pronounced drop in the flux due to the demagnetizing effect, whereas magnetizing effect is really not going to be all that visible.

So, that is the reason why I would see a good amount of armature reaction drop when I am coming to larger and larger armature currents. So this essentially is not considered when I am talking only about the armature resistance drop, armature resistance drop is linear whereas armature reaction drop is nonlinear, it will not be linear because of the saturation effect.

So, what actually is manifested is first there is the drop in the voltage, in the terminal voltage. These are the effects of armature reaction. The second point actually we would see is please note that originally because I was having the lines which are horizontal, I was having the neutral axis which was exactly in the middle.

Now, I have to again drop a perpendicular here so this perpendicular will come out to be somewhere here, so the neutral axis itself is somewhat shifted, I am not going to have the neutral axis any more exactly in the middle of you know the north pole and the south pole, it is coming somewhere you know in a tilted fashion, so please remember I have taken the direction of rotation as anti-clock wise.

So, the neutral axis is also shifted somewhat anti-clock wise, in a generator this will be happen, in a motor it will be opposite, so if I am taking the direction of rotation as anti-clock wise I would have a slide shift in the neutral axis, so I am going to have now brushes are not on the neutral axis any more, it looks as though it is somewhere to one side.

So, the actual current transfer which we call as commutation is going to face some trouble because of this, previously, I had them exactly on the neutral axis. So, I would not have any difficulty basically to transfer the current from plus to minus or minus to plus no problem whereas now I am going to have definitely the conductors which are already not carrying zero current will be expected to change over, because I put the brush there.

So, I am going to have somewhat more difficulty in terms of changing over the current from plus to minus or minus to plus which we would look with the magnifying glass in greater detail about commutation that will be the next discussion after looking at different type of generators. So, we will look at commutation in a greater detail when we are actually looking at the actual current transfer from one commutator segment to the next commutator segment and so on and so forth will be looking at it in greater detail.

Conversation between professor and student starts.

Student: Does the sparking occur because of armature reaction?

Professor: The sparking occurs to some extent because of this, to some extent because of the fact that the machine conductors have inherent inductance. The inductance will not have any effect if it is carrying a steady current.

Conversation between professor and student ends.

Professor: But I am looking at the current transfer from $+I$ to $-I$ when the conductors are defecting from the south pole side to north pole side, so if I am having actually no current at all being carried by the conductor when they are transported from the south pole side to the north pole side and vice versa I would not have had any $L\frac{di}{dt}$.

But if I am transporting the conductor then they are already carrying some current and I am actually pushing them from the south pole side to north pole side, here you go you push them, than $L\frac{di}{dt}$ is not going to keep quiet, it is going to say I will carry the current for some more time no matter what.

So, it is going to carry the current for some more time under heavy opposition from the main poles and that will essentially spill over into the surrounding air. There will be a larger voltage induction, $L\frac{di}{dt}$ will manifest by itself and that is essentially manifested in the form of sparking that occurs in the DC machine. That is why the sparking increases whenever there is a higher armature current.

The sparking will increase when there is a higher speed as well, if you increase the speed you are asking the changeover to take place faster and faster, dt is decreasing, you are looking at $L\frac{di}{dt}$, i is increasing you will see increase in sparking, dt is decreasing you will see increase in sparking, both will contribute to sparking, we will look at this in greater detail when were are discussing commutation.

So, much so for the armature reaction, right now, just the last mention, where ever we are having this dot, if we can have some kind of compensation for that dot by having a cross, can I have some winding there which will immediately nullify the effect of armature reaction, if I can do that nothing like it, all this armature reaction is null and void, so normally in many of the machines which are very-very fussy about the armature reaction, we might put some conductors.

So, this is my pole I may play some conductors which are known as compensating winding. They are compensating for the armature reaction flux, which are cross magnetizing in nature. I am talking about only cross magnetization because the cross magnetization takes place along the curvature of the pole, so along the curvature of the pole if I put some windings along with the pole itself and if I placed them but I want them to carry a current which is in anti-series with the armature current.

So, the armature current is a dot this will be carrying cross and vice versa. So, they we will be anti-series with the armature, so I would have cross as the current here, if I am having dot in the armature conductor. So please understand the connection you are having the armature conductors which are placed in the rotor, the armature conductors connection are brought out through brushes through the commutator and brushes from the brush the compensating winding will be connected, but in anti-series.

So, if I have, I am having probably it is bound in a particular way it should be manifesting itself the dot and cross in the it opposite sense to that of your armature current that is all, so they will be connected in series with the brushes themselves normally, so if I am carrying only 5 ampere of armature current I want the compensating winding also to create a flux only corresponding to 5 ampere.

So, I do not want them to carry a constant current, I want them to carry whatever is the armature current exactly so it will be connected in series with the brushes normally. The same thing will be done for the other pole as well, so if I am having this is north pole, if I am having south pole here I would again had compensating winding here which will be carrying, for example dot, if I am having crosses. So, this is essentially known as compensating winding.

Conversation between professor and student starts.

Student: (27:31)

Professor: It is on the stator, but it will be connected in such a way that it carries armature current which is rotor current. Compensating winding will be along the pole curvature, it will be placed along the pole curvature and it will be essentially carrying a current in the opposite sense of the armature current so that it will be nullifying the armature flux cross magnetizing effect.

Conversation between professor and student ends.

Professor: We will also have something called Interpol which are smaller poles which will be either nullifying the magnetizing effect or nullifying the demagnetizing effect, please remember that the magnetizing effect and demagnetizing effect always take place along the Q axis from the D axis.

So, D axis along the D axis to nullify the cross magnetizing effect we put compensating winding, along the Q axis inter polar region between the 2 poles main poles we placed something called Interpol. So, if the armature reaction is creating a magnetizing effect I will create a demagnetizing effect with the help of Interpol and vice versa.

So, to come back to the effect of armature reaction there is the reduction in the terminal voltage that is the first point the second one is neutral axis gets shifted. The neutral axis get shifted, that is what we saw, so both this thing can be eliminated if I have compensating winding and interpoles, they will essentially make sure that the armature reaction effect is completely nullified if I have appropriate design of interpole and appropriate design of compensating winding.

In which case again the neutral axis will be back to normal the commutation and everything will go on very smoothly, so wherever I cannot tolerate sparking, generally we tend to avoid DC machine itself, if it is possible, still if I have to use DC machine for some reason, then I might like to put compensating winding and interpole although all of them became generally much costlier. If I buy a DC machine without these things it will be less costly as compared to, when I buy it with compensating winding as well as interpole, so it will be definitely costlier.

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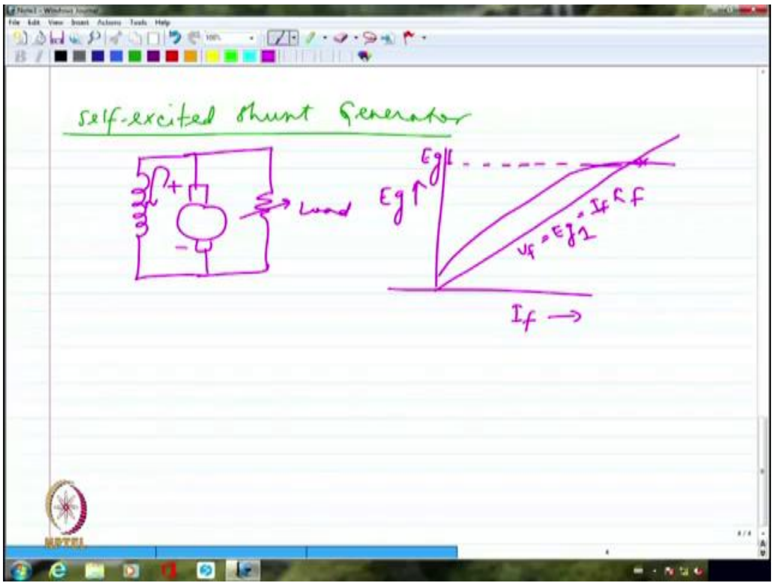

So, now that we have kind of completed the armature reaction and its effect in the case of a separately excited DC generator. Let us quickly look at the first self-excited generator which is a shunt generator, so the self-excited generator as the name indicate you are not going to give a separate excitation at all, no power supply available, all you are doing is just driving the generator and it has to produce electricity, no excitation you are giving, sounds pretty cool. So you are not going to really provide any electricity at all to start even the magnetization.

So, what you will do in this case is you have the armature here and then you are going to have the field coil here, you are not connecting any supply, you may connect a load here that is fine. Initially, you will have some residual magnetism, it will produce a small voltage, that voltage will circulate a current through the field. Residual magnetism let us say is producing a small voltage of 15 or 20 volts.

So, this is going to circulate a current through the field, initially, I may not even connect the load I will say let the voltage built up then only I will connect the load, until then I will not even connect the load in all probability. So, I will have a current flowing through the field that is actually make the current more than zero, definitely originate with zero current, residual magnetism that was producing a voltage.

Now, that voltage will circulate the current through the field, let us assume that, that current is going to create a flux, which will aid, which will aid the original residual flux, so the flux will increase, more voltage, more current, more flux, more voltage, more current, more flux, it will simply build up further and further. It should have hit infinity but saturation comes into effect. So, the flux cannot go beyond the particular value and then you will see that basically you are going to see the voltage is building up but it reaches some value which is dictated by, where I am going to have $V_f = E_g = I_f R_f$.

So, let me say E_{g1} probably, so this corresponds to E_{g1}, so you are going to see that this happens until it reaches an operating point which is corresponding to E_{g1} which will be the point where the field voltage and the armature voltage balance each other, they are connected in parallel, so they are going to balance each other, at a given speed, whatever is the speed at which I am driving the generator, we will continue with the self-excite process in the next class.