Electrical Machines
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Lecture 35
Numerical Session

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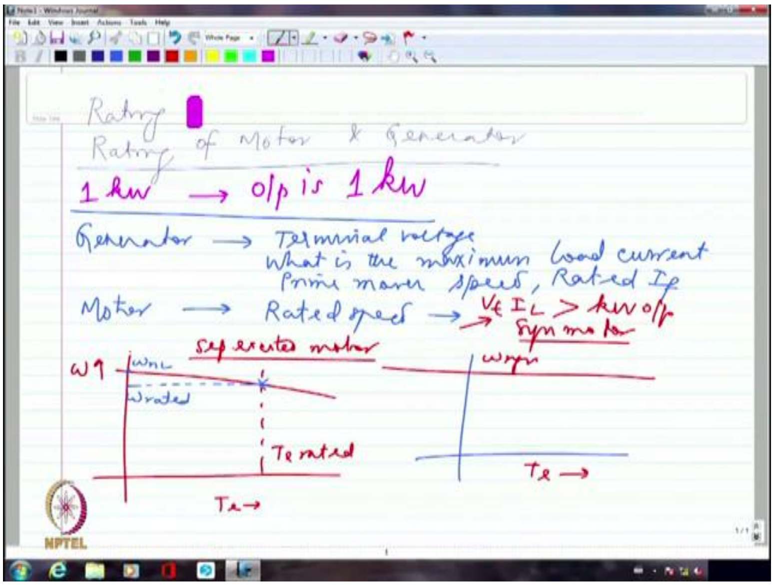

So as far as any machine is concerned the output rating is the one which is actually mentioned on the name plate detail. In the name plate detail is going to say1 kilo watt that means this is output is 1 kilo watt. As far as the DC machine is concerned, we are not going to have any difference between KVA and kW there is no question of any power factor. So whether we look at DC motor or whether we are looking at the DC generator always the power will be given in terms of kilo watt and the power that is given as output.

So if it is generator we are not talking about electrical output and if we are talking about motor we are talking about mechanical output. So if I am talking about a 1 kilo watt machine in general whether it is a motor or generator 1 kilo watt indicates always the output and if it is a generator I will have to specify clearly what is the terminal voltage and what is the maximum load current it can supply?

Because I am going to assume that even if the armature current is slightly higher than the load current because of the fact that there is some amount of field current in a current machine. For example, but the field current is going to be really-really small because of which we can kind of neglect it when we talk about the rating. So I am going to say that this is the load current my machine can supply but when I am talking about how much I can over load a machine?

We generally talk about it in terms of commutator capacity. The commutator is extremely sensitive to any increase in the current. So normally if we it would be able to commutate the current of 10 amperes may be it will be able to commutate until 20 amperes, nothing more than the twice. Generally, many of the DC machine have the overload capability of 2 times the normal rated current that is the way it is where as if I am looking at a motor, I am looking at first of all what is the voltage that I am applying. Because I am worried about the electrical quantity.

So I may specify even here we would specify prime mover speed, what is going to be the prime mover speed? and corresponding to that prime mover speed and a rated field current I will be able to generate the rated open circuit voltage which will be slightly higher than the terminal voltage. The terminal voltage is 220 may be the open circuit voltage can be as high as 230, slightly higher it can be.

So we are going to specify here rated I_f at which the rated voltage the generator voltage will be at rated value which can be slightly higher than whatever is my terminal voltage that is why I am getting regulation. Ideal generator I should not have gotten this discrepancy but because of R_a which is a finite value I am going to have internal drop which is going to cause some regulation in this particular generator.

This is true for any machine whether we talk about synchronies machine eventually, whether we talk about transformer, whether we talk about DC generator where we are talking about electrical output. Whereas if we are going to talk about motor normally we are going to say what is the rated speed, rated speed is achieved when I apply rated voltage to the machine, the machine is drawing approximately rated current and I have given rated excitation and I am drawing rated torque or rated power from the machine.

So everything is at rated condition at that point whatever is the speed that is being achieved is rated speed. So having seen this speed torque characteristics of the machine if he says this is the speed-torque characteristics of the machine, this is ω, this is T_e may be this is what is T_{erated} or T_{Lrated} whatever because they are going to match with each other. Then you can very well note that this is the speed at which the machine is going to run at this particular rate at torque condition.

So this is ω_{rated} whereas this is ω_{NL}, ω_{NL} definitely will be slightly higher than ω_{rated} normally in any machine. This is true in induction machine when it is working as the motor, this is very true in the case of DC machine when it is again working as a shunt motor or separately exited motor, this is not true only in synchronous motor.

Because synchronous motor will run at particular speed or does not run at all. So you are going to have basically the speed to be at synchronous speed no matter what. So you will not have a dropping characteristic at all, you will in fact have in a synchronous machine a steady characteristic like this, I mean it cannot come down it should be a straight line, horizontal straight line.

So this is my synchronous speed no matter what whatever is my torque. This is how the synchronous motor will be. So this is your synchronous motor characteristics whereas this is separately exited or shunt motor characteristics. So in the motor what we specify as electrical quantities will be what is the voltage I am applying that is V_a or V in general and what is the maximum line current the machine can draw? Which will consist of both armature current and field current if it is a shunt machine and we are going to say that this is the maximum kilo watt that it can supply.

So if I say $V_t I_L$ is the total power drawn by the motor this will be greater than the kilo watt output clearly because the efficiency cannot be 100 percent and kilo watt output what is measured is mechanical in nature. So it is torque multiplied by speed and loading a generator you will do it by connecting a resistance if it is a DC generator, loading a motor you will do it by maybe holding the shaft, putting a break.

If it is a grinder you will put more and more material to be ground. So it is essentially causing impediment it is not allowing it to freely rotate. So always when the machine rating is given in the form of output unless mentioned specifically that we are talking about input. The name plate details always give the output. In the case of induction motor and so on sometimes they may say at what power factor it will work under full load condition.

Because induction motor we also said when it is actually starting off on no load the major current drawn is only magnetizing current.

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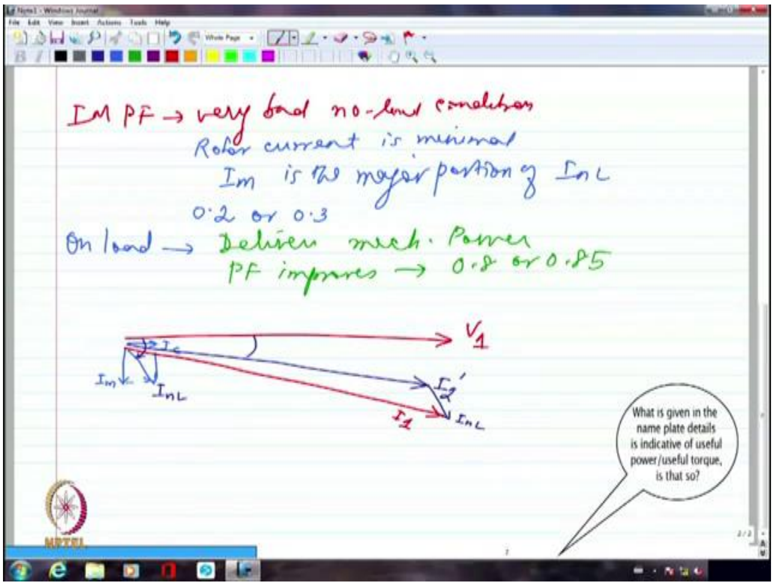

So normally induction motor power factor is going to be very bad during no load condition because what I carry, what the rotor carry? The rotor current is very minimal whereas I am going to have magnetizing current is the major portion of the no load current. So the power factor can be as bad as 0.2 or 0.3. Transformer power factor could also be as bad or even worse because it is not even running, it is not even getting any real power developed.

So no load condition power factor is really-really bad in an induction motor but as we load it, so on load we are going to always deliver a real power, mechanical power. So because of which power factor improves but it can never become unity it will always become may be 0.8 or 0.85 not anything more than that. I am rather saying that we should know the Phasor diagram which is very-very similar to transformer Phasor diagram.

If I say this is V_1, I may have a small core loss component of current, I may have somewhat larger magnetizing current when I add the two is should get actually whatever is the sum which is actually the no load current. Even the power factor I have shown is somewhat better generally it will not be that way, no load power factor is this.

So even that angle I am showing around (60) 65 degree it cannot be like that it will be more than that, normally if it is a well design induction motor. If I look at the rotor current, rotor current I may write it as I_2^l which is very similar to the current that is reflected from the secondary side of the transformer to the primary the same way here from the rotor side it is going to get reflected to the stator side.

But please note in the case of transformer it depended upon what kind of load I connected on the secondary side. Here it is going to depend upon how much load I have put on the shaft if I put more and more load it will require more and more torque, if it requires more torque it will draw more and more current. The slip will be increasing because of which the current will increase.

So here I am going to rather specify what is the rotor current depending upon how much is the load torque on the shaft? So may be if I have a full load torque I may have some current like this, please note this current is still lagging it cannot be at unity power factor because I do have a X_2^l I cannot ignore X_2^l. So I do have X_2^l the overall impedance of the rotor circuit becomes $R_2/s+jX_2$.

So very clearly it is inductive in nature. So depending upon how much is the leakage I am going to have I_2^l lagging behind by some angle depending upon how much is my leakage reactance. Now I have to add these two, the no load current and this particular rotor current when I add them together, so let us say this is my no load current. So when I add them together this is going to be my I_1.

I_1 is the stator current we had been which we had been neglecting conveniently very often we are doing the parallel circuit parameters we cancelled out. But this is what is the Phasor diagram of an induction motor, when I am referring the whole thing to the stator side. So anyway I migrated from the DC machine to the induction motor.

Student: what is given in the name plate details is indicative of useful power, is that so?

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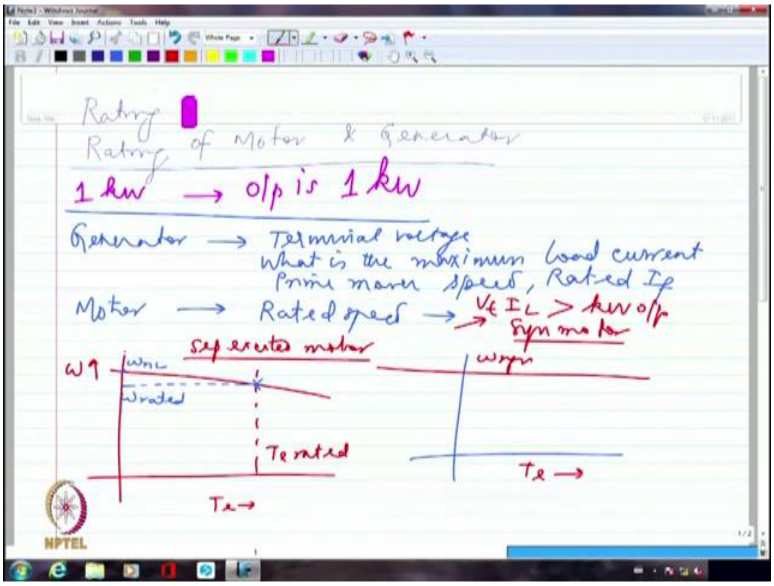

Professor: See again it depends upon the statement generally what is shown on the name plate detail is useful output. The name plate detail always gives you especially as a consumer I would like to know how much my motor can deliver. So that is what is given on the name plate detail. So I should assume that the name plate details are given that is essentially useful output. That is the way it goes generally. Power output and power developed or not the same because power developed in a DC motor will be $E_b I_a$, what you are giving is $V_t I_a$ as far as the armature is concerned, $V_t I_a$ you are subtracting $I_a^2 R_a$ which is the armature resistance drop.

So that dissipation is gone you cannot do anything. So what is left over is $E_b I_a$, that is the power developed minus whatever is the friction and windage losses if those are given. If those are not given I would conveniently assume that it is ideal condition friction and windage losses are 0.

If it is not given, if it is given please do not assume friction and windage losses to be 0. When you are essentially reducing your calculation that is all.

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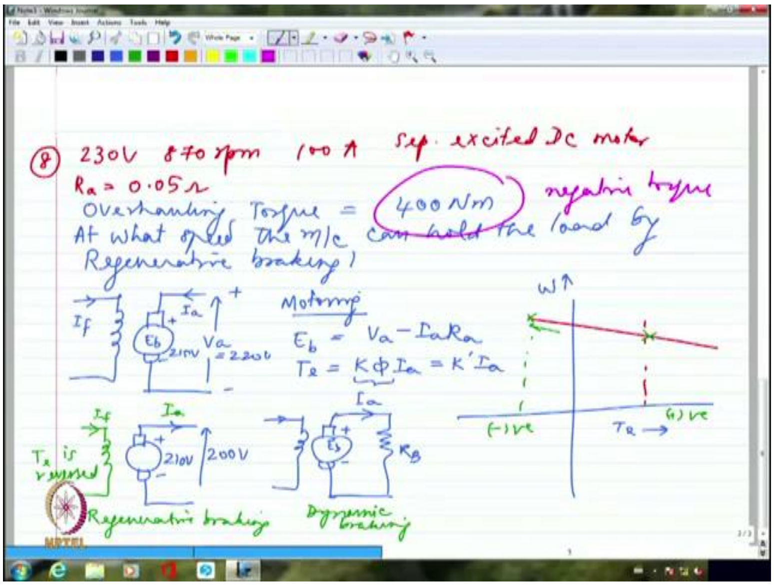

The problem statement says the 230 volt, 870 rpm, 100 amperes, 230 volt, 870 rpm, 100 ampere separately excited DC motor. It has R_a equal to 0.05 ohm. It is coupled to on over hauling load with a torque of 400 Newton meter. Now which says determine the speed at which the motor can hold the load by regenerator breaking.

So at what speed the machine can hold the load by regenerator breaking? So this is what is being asked, first of all I will have to tell you what is the regenerator breaking. So in regenerator breaking normally what we are going to do is, let us say this is separately excited DC machine and I am having field here. If it is actually connected to a voltage supply which is the V_a, normally the current is going to flow like this.

Here is my E_b, so this is normal motoring operation in which case I am going to have $E_b = V_a - I_a R_a$ from which we wrote all the equations and so on and so forth. And field current is a constant because of which we are going to have $T_e = k\phi I_a = k^l I_a$. If I want regenerative breaking to be incorporated, what I can do is either I reduce V_a, if it is like a rectifier I would be able to put a variac or whatever and reduce V_a or if it is like a battery I connected multiple number of batteries I can remove one of the batteries, so that V_a will be decreased.

If V_a is decreased E_b happens to be greater than this decreased V_a. Originally maybe, I had 220 volts here and 210 volts here which is E_b. May be I have decreased this now to 200 volts by removing 120 volts battery and I am not going to definitely have the speed decreased immediately that is not possible because there is inertia.

So I am going to have this to be still 210 volts with plus here and minus here. So what will happen is the current will start flowing in the opposite direction. If the current starts flowing in the opposite direction if there is a battery, that battery is going to get charged. So I am essentially using the kinetic energy stored in my inertia, in my rotational system that is being converted into electrical energy and that is being fed back to the battery or the source in whatever way it is. Because of which I am utilizing the process of losing the kinetic energy rather than dissipating it in the external resistance what I did in dynamic breaking.

If you may recall, in dynamic breaking or rheostatic breaking what we did was to connect a resistance, we had connected a resistance the field was still there but what we did was this E_b was circulating a current I_a which was actually getting dissipated, the current was dissipating the power in form of heat in R_b. This is what we did in dynamic breaking. So this is dynamic breaking or rheostatic breaking because we were connecting a rheostat whereas this is regenerator breaking.

So what is going to happen is I_a has reversed its direction, I_f has not reversed its direction. So torque gets reversed, T_e is reversed. So I am going to have a reversal of torque with the speed still remaining in the forward direction so I would call it as breaking. Only difference between rheostatic breaking and regenerative breaking is, regenerative breaking I am utilizing the kinetic energy.

Whereas in rheostatic breaking I am dissipating that energy in the form of heat, so I am not utilizing it. Our Delhi metro and all that are using actually regenerative breaking because we do not want to lose out so much of energy. So generally we use regenerator breaking to make sure that all the energy is converted back in to electricity and then we utilise it once again that is what we do, wake him up.

Student: How is the energy channelized in electrical machines mechanical breaking?

Professor: It is actually dissipated in the form of heat in the brake shoes that is friction, what you are doing as actually breaking in any of the petrol based vehicle or diesel based vehicle or your bicycle is your putting really some amount of friction you are trying to stop the wheel by putting friction. So it will be dissipated in the form of heat there. That is why if you look at many of the old cars you will see that the break paddle and the brake shoes those worn out very soon because of the heat generate.

You are essentially having again kinetic energy converted into heat but you are not having much control. Because how much of control my leg can have, foot can have in terms of how much of pressing I am doing, it is kind of difficult. Whereas here I will be able to have a control if I try to put a resistance here for example, I can make the current somewhat different. That is not efficiency, if you are talking about quick stopping, may be that gives a quick stopping that is what you think.

But here also if I put a small resistance it will give me a very good stopping control. Electrical braking gives you actually very fine control extremely, fine control that is why the vehicle is generally electric vehicles will have excellent braking mechanism, if it is design properly of course.

So this is regenerator breaking, if I try to show you in the form of characteristics this is the speed, this is the torque and this is going to be my normal characteristics of the DC machine. May be the machine was operating at some point here, this was the operating point that we are talking about. Now if let us say it is something like a vehicle which is going downhill, what will happen? The speed will increase enormously whether I like it or not the speed is going to increase quite a bit.

So if the speed increases quite a bit for what the speed might go beyond rated speed. If the machine is actually going downhill or if it is like an elevator, 4 people have gotten in, it is coming down there is hardly any control let us say, it will just go crash that is what will happen if I do not have any control. But if it is going to go down at high speed I am going to see right away that the torque automatically becomes negative.

You see that this is positive torque direction, this is negative torque direction. So when I am going to have a larger value of speed even more than no load speed that is when regenerative breaking can take place if I am talking about a mechanism where the speed can go beyond no load speed because of aiding of gravity, it cannot happen in a mechanism where it is just moving on a plane because I need to necessarily reduce the battery value, the voltage value otherwise it cannot happen.

So naturally if regenerative has to take place, it has to have a slope or the gravity has to aid the velocity to become higher than the no load speed. So now with this in mind let us try to do this problem. Please understand the moment I say it is over hauling torque that means this has going to be a negative torque because we are talking about breaking. So this is going to be 400 newton meter which is actually minus 400 Newton meter. The torque is going to be

-400 newton meter. So this is 230 volt, 870 rpm, 100 ampere please remember the data.

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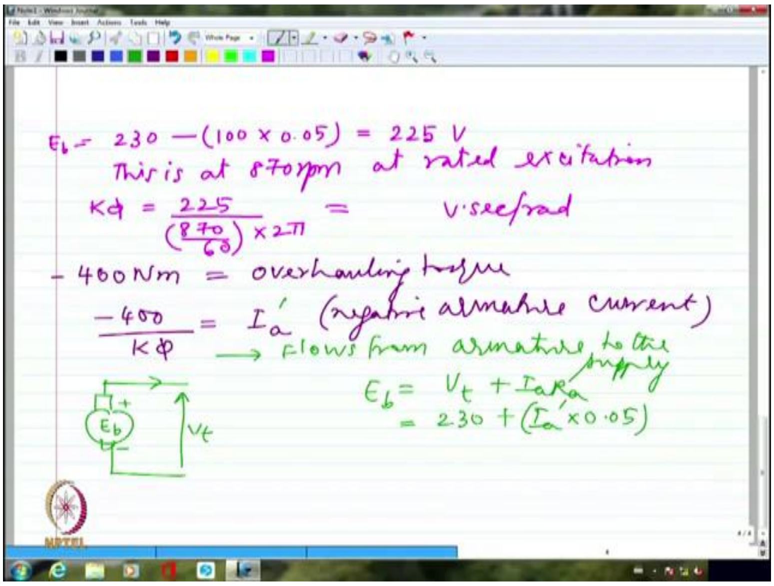

So I had to say 230 minus whatever it is the current because 100 ampere I suppose and how much was the armature resistance? 0.05. So this is going to be my E_b normally. So this is what is my E_b how much is it? 225 volts and it is the 870 rpm and at rated excitation hopefully because we are not taking anything about variation in excitation.

So which means, I can calculate what is $k\phi$. So this will be $k\phi = \frac{225}{(\frac{870}{60})*2\pi}$. So what I get as $k\phi$ is volts per radian per second, so volt second per radian. Now what is being said is 400 Newton meter is the over hauling torque which is actually I should say -400 Newton meter. So I should say $\frac{-400}{k\phi}$ should give me what is the value of I_a, which will be actually a negative armature current.

Which means it is slowing from the armature into the power supply that is what it means, the current direction is reversed. So this flows from armature to the power supply. Now all I need to do is what is the value of E_b under this condition? Please understand that now the current is flowing this way and this is E_b or E_g if it is working as a generator. So I should say E_b under regenerative breaking will be $E_b = V_t + I_a R_a$.

The current is exactly flowing in the opposite direction. So whatever is the generated voltage from that I am going to have I_aR_a drop rest of it is going to go as the terminal voltage. So I can say in this case V_t is still a constant 230, I_a I must have gotten here let me call that as I_a^l, R_a is 005. So I have got clearly what is the value of the voltage. Once I get the voltage I can just divide it by $k\phi$ to get ϖ.

So that is the speed at which it will generate a voltage sufficient enough to create a torque of

-400 Newton meter, that is what it means. I have connected it let us say to a fixed voltage battery, it cannot go beyond or above or in no way it can go beyond 230 only because of that regenerative breaking is taking place, if I have a variable voltage, if I do not have a variable voltage only way it can work is having the terminal voltage as a constant which is what happens in most of the DC motor derives.

If you cannot decrease the terminal voltage what are you going to do? Only way it can happen is if you are armature voltage back EMF becomes higher than whatever is the terminal voltage, that has become higher probably because it is pulled down by gravity. You will get this E_b value to be very clearly greater than 230 because it is $V_t+I_aR_e$. So I_a is governed by the difference between what is E_b and what is V_t? V_t is fixed and E_b depends upon the speed.

So obviously this can happen only at the speed greater than 870 rpm, it cannot happen at 870 obviously. Answer is how much, 921 or something I was getting 920 in fact just 920.4 or something like that.

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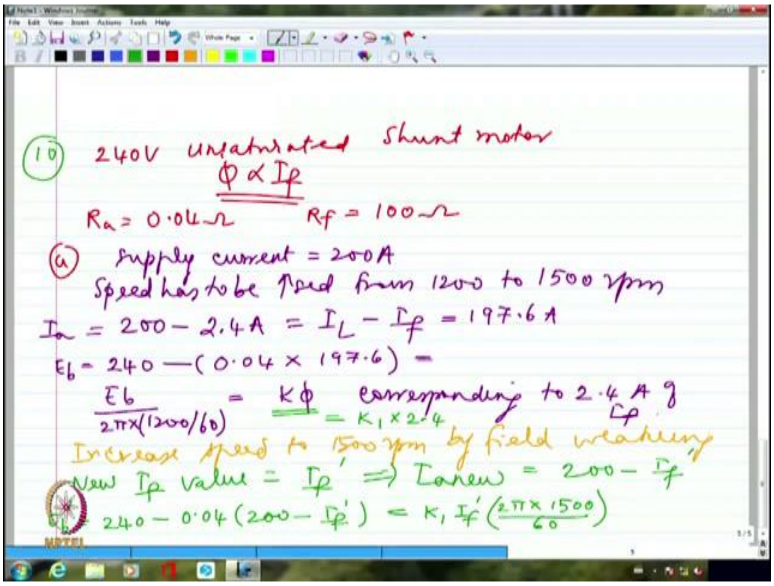

It says 240 volts unsaturated shunt motor that means unsaturated essentially means the flux is going to be proportional to I_f that is what it means. So 240 volts unsaturated shunt motors have an armature resistance including brushes and inter-poles of 0.04 ohms. So I would say R_a is 0.04 and R_f is 100 ohms. Find what resistance must be added to the field circuit to increase the speed from 1200 to 1500 rpm when the supply current is 200 amperes.

So the first abduction says supply current is 200 amperes, speed has to be increased from 1200 to 1500 rpm. So if the supply current is 200 amperes this consist of both armatures current and as well as field current. So I should be able to say first of all 200-I_f, I_f is 240/100=2.4 ampere. So this is essentially $I_a = I_L - I_f = 200 - 2.4 = 197.6A$.

So once I get my E_b I can say I would be able to get my kΦ or kI_f. So I can say speed that is this corresponds to $\frac{E_b}{2\pi * (1200/60)} = k\phi = 2.4A$ of I_f. Now I want to increase actually my speed to 1500 rpm for which I have to do field weakening there is no other way if I do the field weakening I should be able to increase the speed.

So I want to increase speed to 1500 rpm by field weakening. So let us say the new I_f value is equal to I_f^l, line current is not changing so I should be able to say I_a new will be equal to 200 minus I_f^l and I should say $I_{anew} = 200 - I_f^l$. So $240 - 0.04(200 - I_f^l) = E_b^l$ but this has to happen at a value of 1500 rpm.

So I say this rather than writing this as kΦ I can even write this as may be this is equal to kΦ I have got, so this kΦ is actually kI_f^l multiplied by some other constant or I should say this kΦ=

K_1*2.4. So I should be able to calculate what is K_1. So I should be able to write this E_b^l = $k_1 I_f^l (\frac{2\pi * 1500}{60})$. From which I should be able to solve for I_f^l.

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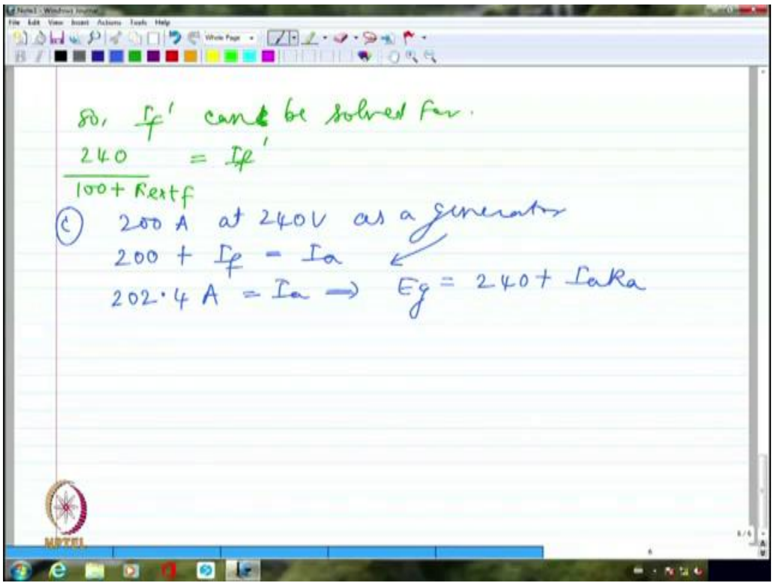

So once I solve for $\frac{240}{100 + R_{extf}} = I_f^l$.

From which you can get what is R_{extf}. if you look at net sub-division the field resistance as an A, so now the field resistance is 100+R_{extf}, always this is all proportion, ratio and proportion kind of problems most of them. So if the field resistance is increase that is in A find the speed when supply current is 100Ampere. You have the field current now I_f^l.

So 100- I_f^l will be your IA from that you will calculate what is the drop $I_a R_a$ and you have got the new value of E_b. So from the new value of E_b you can always calculate what is the speed but only thing you have to remember is I have to use kI_f^l not kI_f. So I think rest of the sub-division will follow it should not be, part C? Part C is generator.

So part C says, if the machine is run as a generator to give 200 amperes at 240 volts. So in part C I am going to have 200 amperes at 240 volts as a generator. So 200+I_f I do not know whether this is with field current as in V or is it field current is in A, I think I have calculated it with field current as in A in my solutions what I have put which is 2.4 ampere. So 200+I_f will be I_a as a generator, so I am going to have 202.4 ampere is I_a.

So from which I can calculate E_g=240+$I_a R_a$. So I would be able to get the generated voltage.

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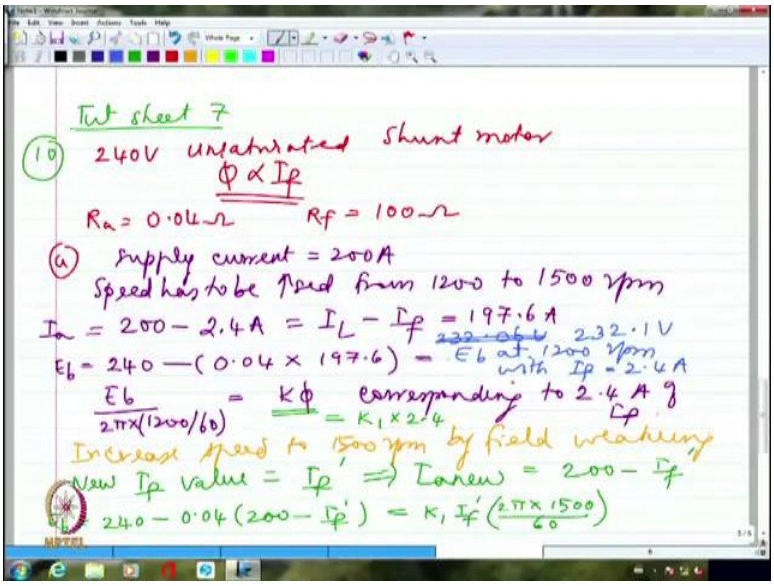

We had calculated what is E_b at 1200 rpm, this is what was E_b at 1200 rpm with I_f= 2.4 ampere. Now the speed is given as 1200 rpm. So I need to just use the ratio again. So I can say this is how much? (200)? 32 something 0.06 whatever 0.096, 232.1.

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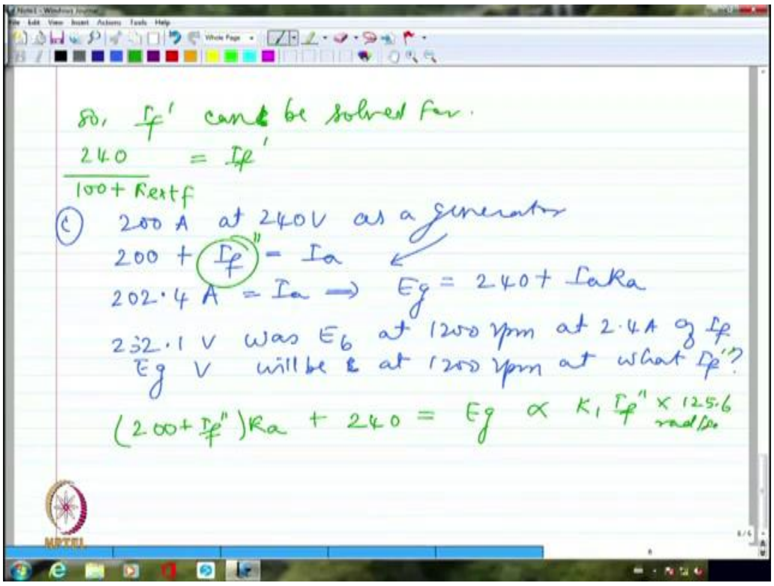

So 232.1 volt so I can say 232.1 volts was E_b or E_g at 1200 rpm and 2.4 ampere of I_f. Now E_g volts will be at 1200 rpm and I_f. Most of them work on ratio and proportion because we hardly ever give the non-linear portion of the magnetization characteristic very often we try to confine ourselves as much as possible to linear portion but if we are going in non-linear portion we may say all though the increase in the current is by so much, armature reaction weakens the flux by so much percentage that is what we say, this is not I_f this is I_f^{ll}, this is also I_f^{ll}. So I should say (200+ I_f^{ll}) Ra+240 =E_g α $k_1I_f^{ll}$*125.6.