# Electrical Machines

**Professor G. Bhuvaneswari**
**Department of Electrical Engineering**
**Indian Institute of Technology Delhi**

## Lecture 21:
## DC Machines – Voltage Build-up and Load Characteristics

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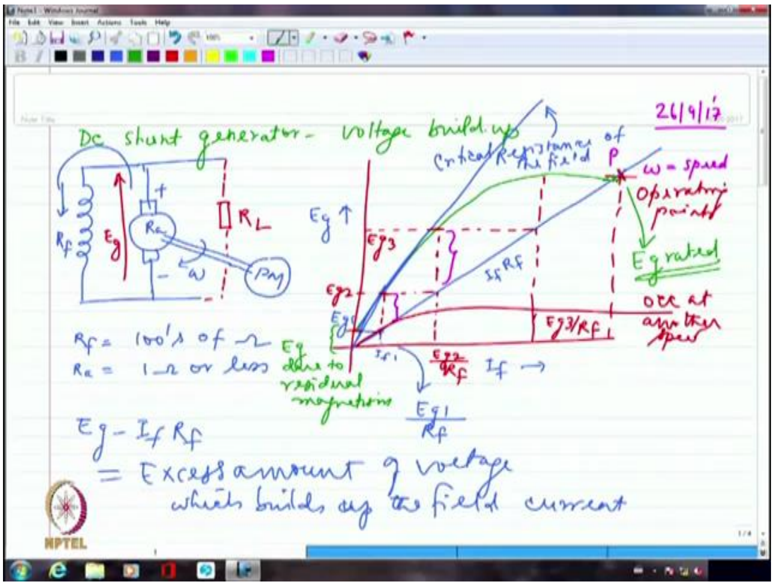


So, we had seen the working of a separately excited DC generator but last class I had started on self-excited generator. So, as I told you earlier in self-excited generator there is no field supply no field supply will be given. So, whatever is the generated voltage that itself has to give the field also a supply. So, what I am trying to say is let us say this is my generator here is the field, so I am going to talk about this as $R_f$. So, I am going to have the field current flowing through this. Now if I want to connect a load I can definitely connect a load here, but I would prefer to connect the load a little later what I mean is let us say I am going to have the open circuit characteristics of the machine is somewhat like this of course the machine has to be driven at a particular speed ω by a prime mover. So, this is going to be my prime mover which is actually rotating this at a speed, so this is my shaft. The shaft is rotated at a speed of ω by the prime mover.

So, let us say this is going to be my Eg and this is going to be my $I_f$ and there is some residual magnetism already existing in my machine even without the field current being of any magnitude. So, $I_f$ is zero at this point and when field current is zero still I will have at least some amount of generated voltage. This voltage may be 10 percent, or you know less than 10 percent or five percent let us say of rated emf. So, rated emf let us say is 220 or 200 V. This is going to be order of about 11 or 12 V. Now, this voltage is generated because this voltage is generated that voltage manifests itself across armature. Let us say this is $A_1$ and this is $A_2$ this is going to be about 12 V to start with. This 12 V is going to definitely pass a current through the field, weather I like it or not it will definitely pass the current through the field. Now, to get a magnitude of the field current. I have to basically draw the resistance line so the slope of this is going to be $R_f$. When this is the current, I am definitely going to have you know for this voltage there will be a field current which will be corresponding to the magnitude of this line. Whatever, the slope of this line that is going to determine the field current. Let us say that is some $I_{f1}$, now if I try to draw the OCC of this machine may be the OCC will be some what like this. This is going to be OCC of this machine. So, corresponding to $I_{f1}$ I am going to actually have a higher voltage generated. So, the voltage generated is going to be corresponding to this value may be this is like 20 percent or let me take some values directly. This is 12 V this may become as highest 24 V so 24 or 25 V have been generated now corresponding to 24 V, now this 12 V have become 24 V, corresponding to 24 V. I am going to have definitely a larger current. So, this was the excess voltage that was available, so I should say $I_fR_f$ actually was only 12 V, but corresponding to this $I_f$ that is $I_{f1}$, I have generated 24 V. So, I have almost 12 V in excess, this is available in excess. Now, that is going to circulate definitely a larger value of current which is corresponding to $I_{f2}$ because of which I am going to have definitely a higher voltage being generated.

So, the higher voltage that is being generated will be corresponding to may be about 40 or 50 V. So, I have got 50 V generated now. Now corresponding to 50 V if I try to look at the field current, I am going to have a much higher field current. This field current is $I_{f3}$, so initially I started off with zero Ampere field current maybe it become 0.1 A. This will be probably 0.5 A and this has become almost 1 A of field current. At 1A of field current I would definitely have a higher voltage generated. May be this is as high as 150 V or 130 V. Now corresponding to this value of 150 V the field current has increased quite a bit but look at this previously I have an excess voltage of 12 Volts or something. Now I may have an excess voltage of 25 V. Now I am going to have an excess voltage of much higher voltage which is actually 100 V.

So, this is corresponding to $I_{f4}$, so this current can be as high as let us say 1.8 A. Now, corresponding to this I am going definitely have a higher voltage but please note I have already attained close to saturation because of which the voltage has increased only slightly may be 118 or 119 V. Now, with this when I go to a little higher value of field current. So, let us say this is $I_{f5}$ which is may be 2, 2.2 or 2.1 A. I would have reached maximum value of actually 200 or 220 V.

So, where ever this open circuit characteristics is intersecting with the $I_fR_f$ or load line of the field circuit that is where I am going to arrive at really the operating point. So, this will be the operating point of the generator. Where $I_fR_f$ will become equal to $E_g$. So, there is no excess voltage available at all. So, please note the initial operating point was this from that it went to a higher field current. From which it stepped up to this particular value then from here so I can say this was the operating point $P_1$ then it came to $P_2$ then it came to $P_3$ from there it came to $P_4$ then it went to $P_5$ from there it when to $P_6$ which is the final operating point.

So, the voltage is building up slowly because of the excess voltage that was available to circulate a higher and higher field current through this that is the reason why the voltage ultimately reached this point. Now once it reaches this point, we can actually afford to connect the load. That is when we are going to connect the load. So, this particular resistance value this is $I_fR_f$ line I told you, so the slope of this line basically is going to give me whatever is the resistance value. So, if I measure what is the actual slope of this line, this particular line which is tangential this is known as critical field resistance or critical resistance of the field circuit. So, this particular slope of this particular line or which is tangent to the curve OCC, I call that as the critical field resistance, if the resistance is below this, we can have voltage build-up, it should actually start from… Yes, thank you for pointing out. It should have been somewhat like this, it should have started from the origin, obviously.

Student: (())(2:02)

Professor: yeah. But the voltage what you are getting is miniscule compare to what you got in the residual magnetism, so it is going to be really-really small. So, you would not have anything to write home about that is what we are trying to say basically, so you are not going to have sufficient voltage coming up as the generated voltage when the resistance of the field circuit is greater than or equal to that of the critical resistance.

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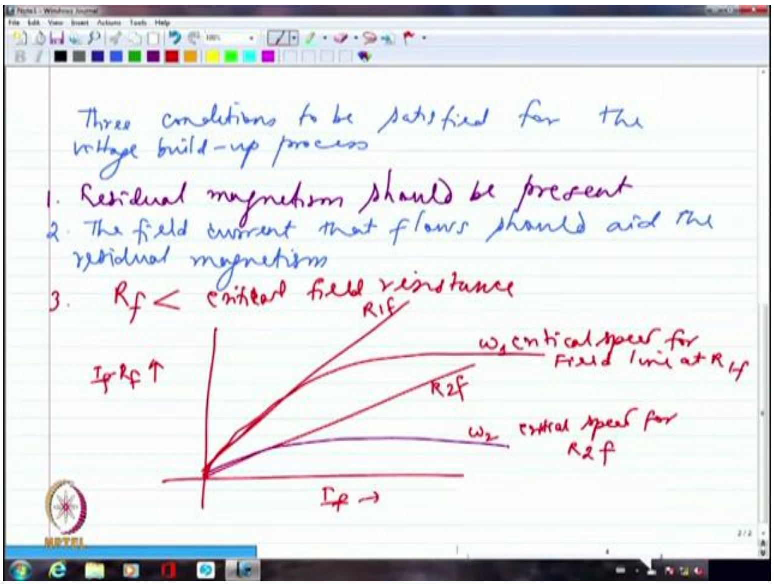

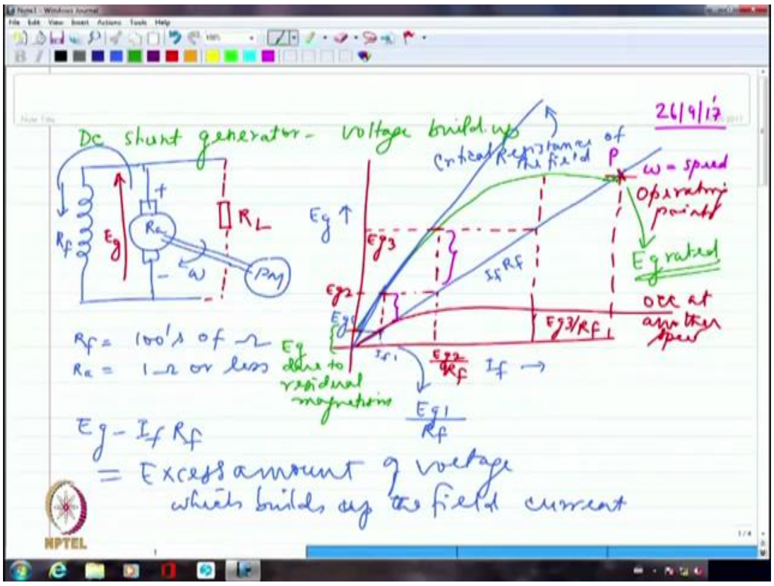

So, I would say for the voltage build-up process mainly three conditions need to be satisfied, three conditions to be satisfied for the voltage build-up process in a self-excited generator. The first thing is unless I have a residual magnetism, it is definitely not going to work because I am looking at field current equal to 0, the field current raises from 0 value only because of residual magnetism generated voltage, so for sure I should have residual magnetism. So, residual magnetism should be present, that is the first thing that needs to happen.

The second one that I want would be, once the residual magnetism kind of generate some voltage whatever is the current that is flowing, so we said that the current is flowing in this direction if I say this is plus and this is minus, this is how the current is going to flow. So, this current what is flowing through the field circuit should aid the residual magnetism, it should not kill the residual magnetism. So, the current that is flowing in the field circuit because of the voltage that is being generated should aid the residual magnetism.

So, that the flux builds-up further and further, if it is not really aiding, it is rather opposing the entire thing is suicidal, right, it is not going to really work any further so, I should have basically the field current that is flowing should aid the residual magnetism. Or the flux should build-up further and further if that does not build further and further, we are going to have a problem of suicidal operation of the generator so the voltage will be killed, basically.

And the third thing is the resistance of the field circuit should be less than that of critical field resistance. So all these three things should be valid only then the self-excitation process really you know can go ahead, I can also say that if originally my field resistance line itself is like this I have got the field resistance line which is $I_f$ versus $I_fR_f$, which is indirectly $E_g$, $I_f$ times $R_f$ we are taking it as $E_g$ so this is the field resistance line by chance if I am driving the generator at a much lower speed.

If I am driving the generator at a very-very low speed, then also the intersection point will not be really good enough for me to get any perceivable voltage. So, if I am already given the field resistance line I should be able to draw the OCC for this particular generator may be I have to draw it to particular speed. I can bring down the speed further and further and I should be able to say for this field resistance line if I go below this particular speed, I will not get really voltage build-up process possible.

So, if I try to draw it, for example, in the previous page so I had drawn this as the resistance line, first start with so may be if I had, the OCC at another speed, may be so that may be really giving me much lower value of voltage which will come up for this particular generator operation. So, I may not be able to really see any proper voltage. So, this will be even more visible if I try choose the resistance line, probably somewhat like this, if it is at a higher value then I can show even better characteristic. So, this is the critical speed for field line at say $R_1$, I may say this is $R_1$, so this is $\omega_1$ may be this is $R_2$ and let me call this as $R_{1f}$ $R_{2f}$, I am talking about resistance of the field, so I am writing $R_{1f}$ and $R_{2f}$ and so on.

This $\omega_2$ will be the critical speed for $R_{2f}$, this is how it will be. So, I am going to have basically you know a critical speed defined for a given value of field resistance similarly, critical field resistance defined for a particular value of speed. So, I would be able to do both in a field circuit but in general we drive the generator at rated speed, whatever is given as the rated speed, so for that whatever we are defining as the critical resistance of the field circuit that we say as the critical field resistance for that particular generator with that particular rated speed, as simple as that, so much so far self-excitation process in a shunt generator. Let us try to look at the external characteristics for a shunt generator.

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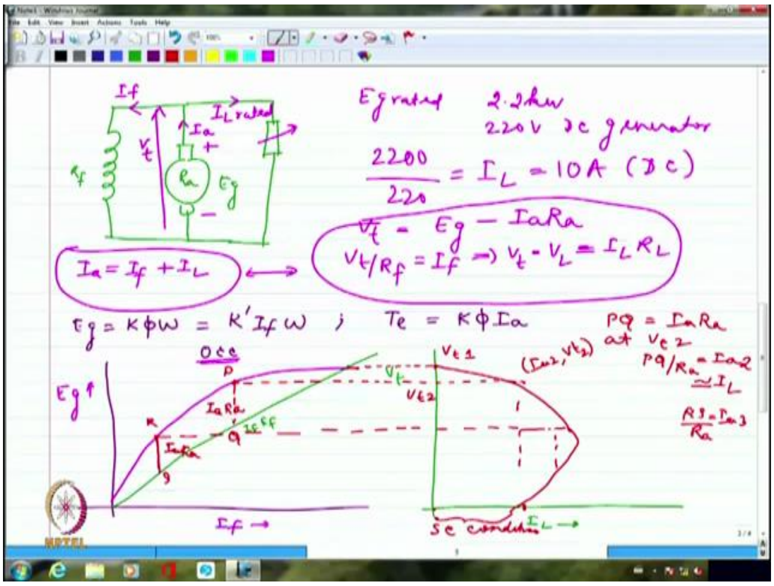


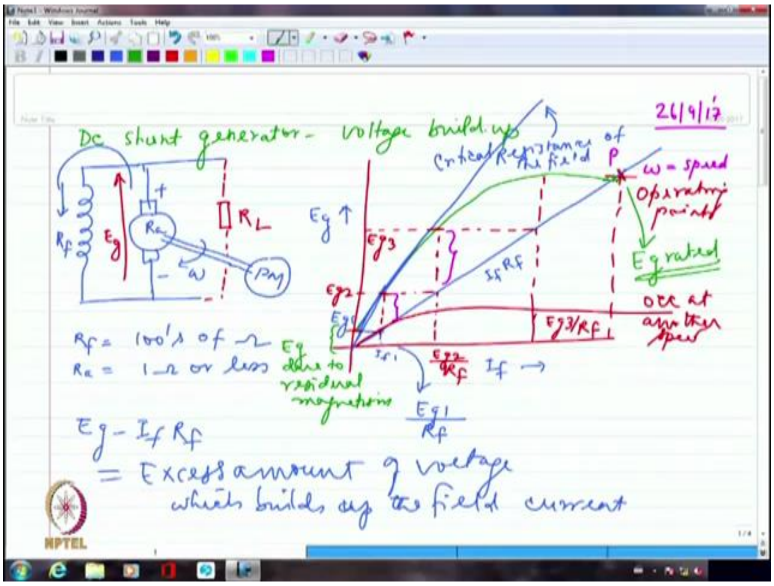


So, let say I am taking up the circuit of a self-excited generator shunt and I am going to take this as the load. So, now, I am connecting the load as well. Please note that I will have an internal resistance of $R_a$, very clearly, I am going to have the field circuit resistance $R_f$. I can definitely include an external resistance $R_f$ external, if I want provided, I want to control the field may be beneath whatever is the normal value of field current that will flow because if I include an external resistance the field current will come down.

So, if want to reduce the voltage for some reason, then I might have to include an external resistance in the field circuit so, that I get less and less value of field current. I am talking about this with respect to the inherent value of field resistance. I am not included any external resistance. So, I am going to have basically $E_g$ as the generated EMF without any $I_aR_a$ drop. If I do not have any $I_aR_a$ drop I am driving the machine at rated speed it will ultimately settle down at the point $E_g$ where the resistance line will intersect with OCC, both of them are intersecting with each other and I get the operating point somewhat like this.

Let us go to the first one so we said this is the operating point what we get is the intersection between the OCC and the field line, both of them are essentially intersecting with each other to give me that point. So, let me call this as $E_{grated}$ when I am driving the machine at rated speed and it have gone on with inherent field resistance and it has finally settled at the point which is corresponding to some value $E_g$ which I call as $E_{grated}$.

So, I would say that now I have allowed the machine to reach its own operating point because of which we have reach $E_{grated}$. Now, I am going to connect the load this may be a variable load but let us say I am actually connecting it corresponding to a current that will be drawn which is $I_L$rated. For example, let us take our regular rating 2.2 kW, 220 V DC generator, please note what is given as 220 V is generally the terminal voltage we do not know about the internal voltage it is going to be very difficult from it to measure the internal voltage because hardly ever I will run a generator without a load.

I will always connect the load so the 220 V what is given as normally under the condition of full load what is the terminal voltage. So, we are looking at the terminal voltage as 220 V, 2.2 kW is the output. We are going to have an output in the DC generator which is an electrical output that is going to be 2.2 kW, so in which case I can write away say, $\frac{2200}{220}$ is going to be the load current. It is DC, no power factor so I can directly calculate basically the current as 10 A.

So, basically, I am going to have a current of 10 A flowing through this. Even if I assume probably that $R_a$ is 0.1 Ω very-very small, still I am going to have at least 1 volt drop as $I_aR_a$ drop. So, what originally the machine would have generated would have been may be 221 V out of which 1 V is dropped and I am getting 220 as the terminal voltage. So, based on this I should be able to write the equation somewhat like this, if I say this voltage is $V_t$, I am going to have $V_t = E_g - I_aR_a$.

Because internally whatever is the drop that is happening within the armature devoid of that whatever is available that is what comes out as the terminal voltage. And similarly, I should be able to write $\frac{V_t}{R_f} = I_f$ and I can say also $V_t = V_L$ which is also equal to $I_L R_L$, if I am assuming I am connecting a resistance load, so I can simply say it is $I_L R_L$, instead I could connected a motor.

The generator could be feeding a motor but right now, I am just taking a passive load which is a resistance load. Apart from this if I say this is $I_a$, this is what is supplying actually the field current as well as the load current. There is no other source, so obviously my generator has to supply both of them that is why I call it as a self-excited generator. So, this is plus, and this is minus which is working like a voltage source. So, I am going to have $I_a = I_f + I_L$.

This is going to be my armature current. So basically, we are writing KCL that is all, nothing more than that. So, these are the equations which govern the operation of the shunt exited DC generator, all of them put together they are going to govern the operation of a shunt exited DC generator, of course, we have the fundamental equation what we initially derived $E_g = k\phi\omega$, which is actually equal to $k^1 I_f \omega$, if I assume in that particular operating point $\phi$ is equal to some constant multiplied by $I_f$.

At that particular operating point and I am going to also write, if I look at what is the torque, electromagnetic torque which will be generated within the generator, which is actually a counter torque. So, this counter torque is going to be some $k\phi I_a$. So, both these equations are very much valid whether it is a generator or a motor, only thing we will say in a motor we will call this $E_g$ not as $E_g$, we will call that as $E_b$, back EMF or counter EMF, and we will call basically the torque as electromagnetic torque which becomes the output torque in the case of a motor whereas it is a counter torque in the case of a generator that all is the difference..

Now, let try to draw the external characteristics for this self-excited generator. So, let me draw first of all what we drew as the OCC because from which we are going to derive how the external characteristics look like. So, this is my $E_g$, this is going to be $I_f$, so I am probably going to have this as my OCC and let me probably look at the resistance line, somewhat like this, so this is going to be the $I_f R_f$ characteristics.

I am showing very-very small margin so we may not be able to really load the generator much, but never the less. Let us try to probably look at how we are going to go about drawing the external characteristics. So, let me probably take neither x and y axis, where I am going to draw the external characteristics. When I draw the external characteristics, I am going to look at the terminals basically so which means I will, I am more concerned about the load.

So, I have to look at how much is the load current in one sense, and I have to look at how much is the voltage that is available which is $V_t$ or $V_L$ in another sense that is it. So, let me look at first of all under no load condition, so this is the operating point, so let me take probably this as the starting point of my characteristics which is actually may be $V_{t1}$ at $I_L=0$. Now, if I look at another voltage, maybe I just want to look at this voltage, so I am going to take this as the voltage which is being you know taken off to the external characteristics, so let me call this voltage as $V_{t2}$. At this point if I look at it this is the generated voltage, this is the load resistance, field resistance line.

So, this is the only margin I have, so if I may call this as the margin, PQ is the margin I have, are you getting my point, because whatever is available this is basically the margin what I have in terms of building up the field current even earlier, so I should say this corresponds to actually the $I_aR_a$ drop. So, if I assume roughly $I_a$ and $I_L$ are equal, they are not definitely $I_a = I_f + I_L$ but, it is very difficult for us to every time subtract $I_f$, otherwise you have to directly subtract $I_f$ as well. I know what the armature resistance is so should be able to get what is my $I_a$ because I know this PQ length so, PQ is actually $I_aR_a$ at $V_{t2}$ terminal voltage.

So, I am going to essentially get this $\frac{PQ}{R_a}$ is going to be $I_a$ which I am approximately assuming it to be $I_L$. I can assume $I_a = I_L$ in variably because $R_a$ is going to be really-really small most of the times that is going to be only 0.1, 0.2 whereas the field resistance is going to be 150 Ω or 200 Ω and so on. So, if I look at normally 22 kW generator, I will probably have hundreds of amperes of current through the armature, but I will have only 1 or 2 amperes of current through the field which I can afford to ignore. If I am talking about full load condition, for example so, roughly I am ignoring because of which I should be able to get let me call this as may be $I_{a2}$, so I have to look for where $I_{a2}$ is and probably this is one of the points which is corresponding to $I_{a2}$, $V_{t2}$. Similarly, I can take the third point, may be let me take the third point here, what I have is now, this much as the leverage, what I have is this much as the leverage, so that corresponds to the $I_aR_a$ drop, so I am ignoring to have essentially this as the $I_aR_a$ drop and I am going to have basically this $I_aR_a$ drop if I try to get this as $R_s$.

So, I am going to have Rs divided by whatever is my Ra this will be may be Ia3, so I am going to have may be slightly higher current or whatever. So, I have to essentially derive point by point and then I should be able to basically get so, this was my second point, this was my third point, may be my external characteristics will be somewhat like this, and finally it may end-up under short circuit condition, if I just short circuit the load terminals, voltage will be 0, if the voltage is 0, that means I am not getting any terminal voltage at all.

But, may be that is some internally generated voltage for sure so, corresponding to the internally generated voltage I will have $I_a R_a = E_g$. That is all I will get, and because it is $I_a R_a = E_g$ I am getting 0 voltage as the terminal voltage, because $E_g - I_a R_a$ will be $I_a R_a$ minus $I_a R_a$ which will be 0 V, so this is my short circuit condition. So, whenever I have a short circuit condition, I can probably end up in that inadvertently, not intentionally.

May be by some chance it has become a short circuit, despite being under short circuit condition, I am going to have automatically the generator protected against over current, the current will not be extremely large in a transformer we said, if we short circuit we are going to get 40 times, may be 30 times the rated current that cannot happen in self-excited generator because the field current also depends upon the terminal voltage.

The moment I short circuit the generator the terminal voltage will become 0, because the terminal voltage becomes 0, I am going to have very clearly the current limited by the fact that the field current itself have now becomes 0.

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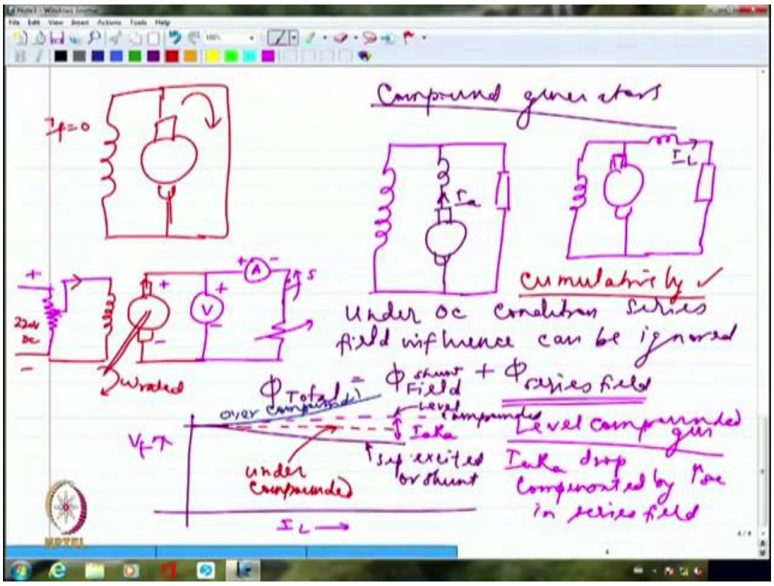

If I actually have two parallel path once I have 150 Ω resistance which is actually the field resistance and on the other side I have short circuited where will the current go, all the current will go here, no current here, so $I_f$ will be equal to 0, so if $I_f$ is equal to 0, automatically I have come back to the residual magnetism voltage nothing better than that. I am not going to get anything more than the residual magnetism voltage, so the current I get depends now upon what is residual magnetism and what is the value of armature resistance.

So, I am going to have $E_g$ which is generated with respect to residual magnetism divided by Ra which is the inherent armature resistance and that is going to give me definitely not a very large current, it is going to be smaller current which will automatically protect you know my machine against any short circuit condition, so self-excited generator normally have this major advantage that inadvertently if there is a short circuit across the terminal of the generator automatically it will be protect against any over current, because the over current will be still limited by whatever is the voltage that is generated only due to residual magnetism.

So, this is one of the major advantages of self-excited generator. Never the less in separately excited generator invariably we have a complete control over the field which allows me to probably build-up the voltage quite easily, whereas in self-excited generator I am limited by critical speed, I am limited by critical resistance of the field and so on and so forth. I do not have a complete control over the field current, that is going to be one of the negative sides of self-excited generator. But self-excited generator is quite commonly used because of the fact that I do not need a separate excitation source.

Wherever, DC generator may be needed it is easier to use a self-excited generator rather than separately exited generator. So, when we conduct the experiment on the laboratory little bit of introduction I will give you for that, what you will have is basically a DC generator, may be separately exited DC generator, this is generally connected to multiple number of motors, we have on one shaft two DC machines, one synchronous machine and one induction machine all of them connected you know in one shaft, so only one shaft when it is rotating all the four machines will be rotating simultaneously.

So, if I have one of the machines even working as a motor, as a prime mover which is imparting mechanical power it is good enough, so I am going to have may be an induction motor working as a prime mover, may be a DC motor working as a prime mover, and then I am going to give a speed of ω which will be rated speed. So, this will be run at rated speed and I will make sure that this field current is controllable, if I have to have the field current as controllable, generally what I would do is to connect the potential divider preferably.

So, if this is my potential divider I will connect here, this variable point I will connect to one of the movable points. So, I am going to apply basically plus minus may be 220 V DC. For example, so if I bring down this voltage to 0, hardly any resistance included in the position, I would get literally 0 current going through the field circuit, so what is the voltage that will be generated will be residual magnetism nothing more than that.

So, what I would do is to put a DC, so I am going to put a DC voltmeter here1, and I will also but a DC ammeter here, and I will put a load which is variable. This is how it will be connected, and I am assuming that this is plus, and this is minus of the generator. So, initially for OCC. I will have basically if I put a switch here, I can open the switch no problem. I have a switch here, I can open the switch so it will be on OCC I can slowly increase the field and then I can look at what is the voltage generated at rated speed so I will get completely the entire characteristic which is OCC until I reach the rated value of voltage I would not definitely over load the machine beyond at.

If it is rated for 220, I would like to go until 220 and then see that I stop, here. That is what we do for OCC for the load characteristics now I will close this switch, so this will be closed and after closing the switch I had kept the excitation at rated value, I have kept the speed at rated value. Now, I have to slowly vary the load note down what is the terminal voltage versus load current. That is about it, so that tells me really what is the internal drop that is taking place.

So, this is essentially for how to experiment on a DC generator. Just to add on to this point I should say there are compound generators, so we have looked at separately exited generator, we have looked at shunt generator, we are yet to look at compound generators. So, in a compound generator I am going to have basically a series field as well as shunt field. So, I have a shunt field and series field and I will connect the load here.

This is what I have shown is the long shunt connection as I mentioned may be two three classes ago, short shunt is only across the armature, it will be connected only across the armature, so let me draw the short shunt as well, so I am going have only across the armature, I have this connected and then I am going have the series field along with the load as well. Please note in short shunt, I am not going to have any series field current at all if the load is open.

So, under open circuited condition I will not have any series field current whereas in long shunt I will have even if the load is open circuited, I will have a small current which is field current, but field current is generally very-very small because of which I can ignore it. Series field influence on the overall main field will be negligibly small when there is no load. So, under open circuit condition in general I can say under open circuit condition series field influence can be ignored.

So, I do not have to really look at the series field influence at all because I am not going to have any perceptible or perceivable current through the series field, it is going to be really-really small whether it is long shunt, in short shunt any way it is going to be 0, so I should say in general, the series field will be directly affected by the load if the load increases I am going to have the series field current increasing, if the load is decreasing the series field current is going to decrease.

That is why we said generally you can say in general the series field is called the series field because it is in series with the armature and it is going to carry the same current, roughly the same current as that of the armature current. Of course, in this case you can say the series field is going to carry only the load current whereas in this case it is going to carry the armature current. So, I am going to have basically armature current coming up here whereas I am going to have here only the load current coming up.

So, we are going to have basically the current going like this. Now, if I have the series field aiding the shunt field, both of them are additive, what I mean is I have some series field flux created, shunt field flux also created, both of them are aiding each other, so if I look at the total main field flux, the main field flux is addition of the series field flux plus shunt field flux. So, if I have $\phi_{Total} = \phi_{ShuntField} + \phi_{SeriesField}$. What I mean is, this is shunt field, of course, $\phi_{ShuntField}$ and $\phi_{SeriesField}$.

Then I am going to have as the load increases, I am going to have more and more flux coming up what we drew as the external characteristics for the separately excited generator, for example, we said that we will have a drop like this. Originally if the generator had been ideal, I would have had constant voltage, but it is not really ideal because of which I am going to have a drop in the terminal voltage, and this drop we said is roughly $I_aR_a$ drop. Of course, there will be some armature reaction drop currently I am not considering, I am only looking at $I_aR_a$ drop.

If I am able to compensate for this $I_aR_a$ drop by providing adequate amount of series field. Then I will get a flat characteristic as per as the voltages is concerned, if I am going to have enough amount of series field influence on the overall field to compensate for the $I_aR_a$ drop, I will get almost a flat characteristic irrespective to of the increase in the load current. That kind of a generator is known as level compounded generator. So, I will have level compounded generator, if I am going to have whatever is the $I_aR_a$ drop this is compensated by increase in the series field, whatever is the increase in the series field if it is compensating for the $I_aR_a$ drop, then I can say the voltage the terminal voltage is going to be almost a constant.

If I have some series field influence but it is not good enough to compensate for $I_aR_a$ drop, let us see $I_aR_a$ drop is 10 V, whereas the series field voltage generated is only 8 V or 7 V, then I am still going to see a drop and may be the characteristic will lie somewhere in between the two, so the series field influence is not good enough to completely compensate for $I_aR_a$ drop, but it is partially compensating.

Then, we are calling that as under compounded generator. I am not really providing the complete compensation for the $I_aR_a$ drop, I am only providing partial compensation, so I would call this as under compounded. This is just the separately exited or shunt, this is roughly the level compounded, if I say roughly, I am getting a flat voltage, flat compounded or level compounded, some people use it as flat compounded also because it is a flat characteristic, horizontal characteristics. If I provide more amount of series field compensation than the $I_aR_a$ drop as I load the generator more and more, I will see a steady increase in the voltage as long as the saturation does not interfere.

So, I may have actually the voltage slowly increasing that is essentially known as the over compounded. Under compounded is less amount of compensation given, over compounded is, you know, more amount of compensation given, and level compounded or flat compounded is just sufficient amount of compensation given. So, this we will call as over compounded.

So, in all these cases please note that the total flux what I am getting after I pass the current through the series field also is more than the original shunt field flux, so I am going to have the total flux greater than whatever was the original shunt field flux, so this is actually added cumulatively so we call this as cumulatively compounded generator in general.

So, cumulatively compounded generator refers to where the series field and the shunt field aid each other if, both of them aid each other I am going call that as cumulatively compounded, so under cumulatively compounded I have three configurations one is level or flat, the second one is under compounding, the third one is over compounding. So, obviously if I am specifically mentioning about cumulatively compounded there should be may be another configuration where they will oppose each other.

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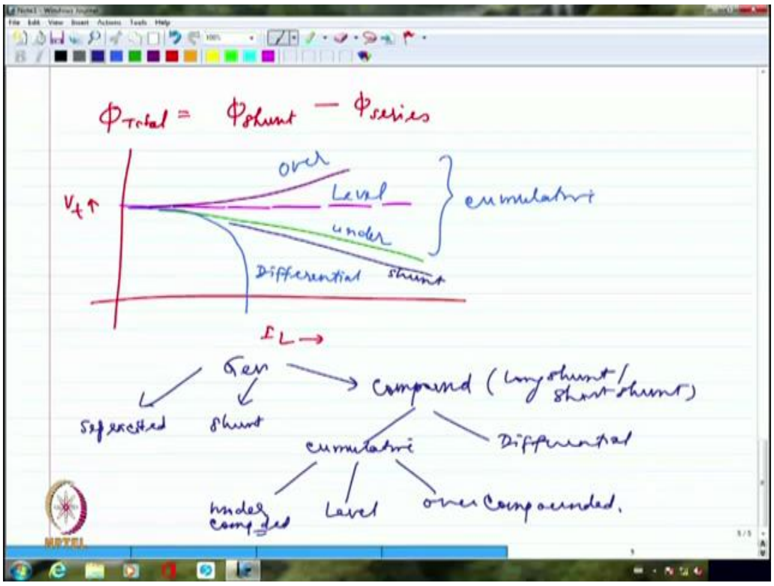


So, I have one more configuration which is actually $\phi_{Total} = \phi_{ShuntField} - \phi_{SeriesField}$. So, you bring down the voltage drastically, whenever, I load the generator the voltage is going to drop pretty drastically not only, $I_aR_a$ drop is depleting the voltage but, the series field is also trying to deplete the main field itself because of which I am going to have lower and lower voltages.

So, if I draw the characteristic, let me draw it once again I am looking at $V_t$ versus load current and if I draw for level compounded, I am going to draw it like this.

If I draw it for over compounded, I am going to draw it like this. If I draw for under compounded may be I am going to draw it like this, and if I am drawing for differentially compounded DC generator, literally is will reach 0 V. When I load it to the fullest extent, so this is differential, these are all cumulative with this being under compounding, this is over compounding, this is level compounding and somewhere in between I should draw the normal shunt, just shunt alone no series.

Student: (())(41:20).

Professor: That is cumulative all of them correspond to cumulative, cumulative is the condition where the series field and shunt field are added together to give me the total flux. This is another type, so I have basically if you look at the DC generator configuration I can say, of course, one is separately excited we have seen that already, and the second one is shunt, the third one we called was compound. So, inside compound generator I can have long shunt short shunt this is depending upon the connection.

But, in this itself, I would say there are two, one is cumulative, the other one is differential, under cumulative I talked about three, one was under compounding, the next one is level, the third one is over compounded, right, is this clear, So, with this we are completing basically our discussion on the compound generators. One small topic, that is left over is the series generator after which we will branch over to motors. In motors also we have all these classifications.

Now, that we have understood generator, hopefully motor should be simpler, so we look at motors and then at the end of motors I will discuss commutation in really great detail. So, with that we will conclude our discussion on DC machines itself, after looking at the speed control breaking everything for the motors.