Electrical Machines - II
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Lecture - 54
Circle Diagram (Contd.)

Welcome and we were discussing about the Circle Diagram of a three phase induction motor. We first did the circle diagram for a very I mean based on simplified equivalent circuit we developed the circle diagram, but now we want to take the effects of all the other parameters as well. And I told you that the equivalent circuit for this type of circle diagram will be based on this type.

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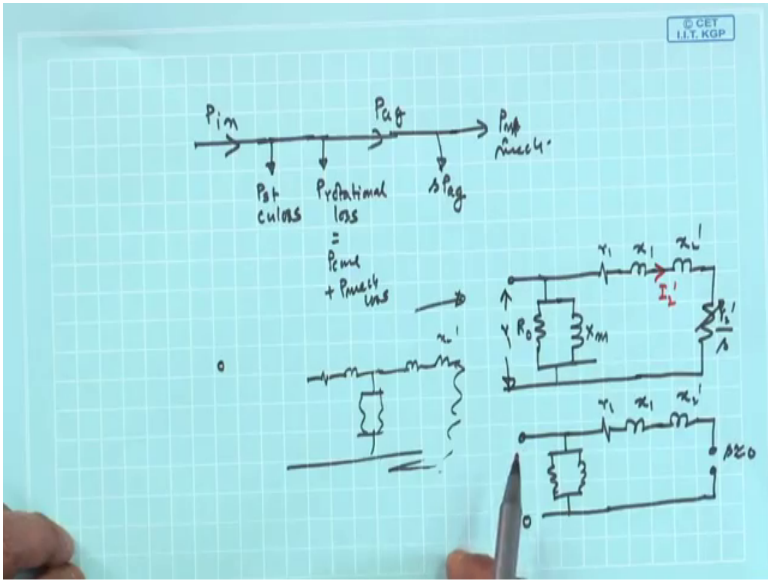

That is the parallel branch is brought in front of the supply per face v 1 R naught X m these R naught will represent both the frictional loss and things like that. And therefore, so far as this equivalent circuit is concerned you see this will be your then I 2 dashed and here these parameters are fixed; one resistance is varying.

In fact, the r 1 can be also neglected as if it is this resistance will be varying I want to find out the locus. Anyway that will be once again a circle why not, but the total current drawn from the supply will be equal to this I naught plus I 2 dash.

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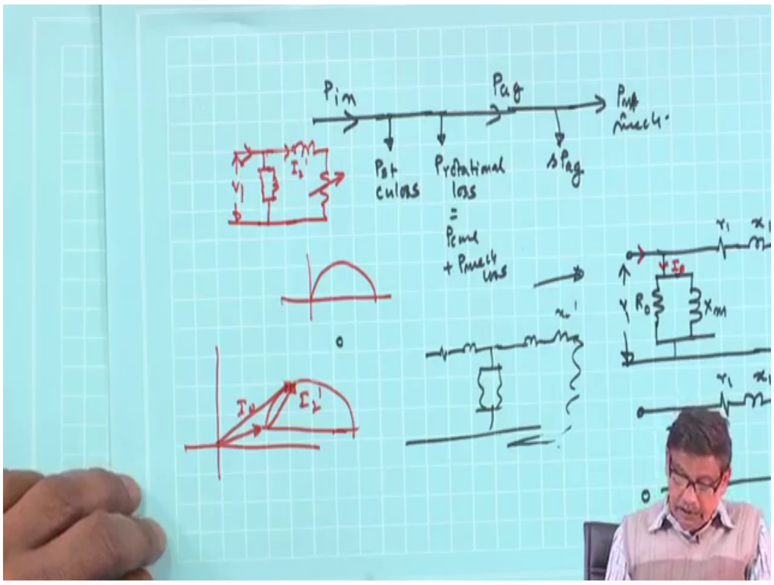

Therefore, and since you know in a circuit suppose there is x there is r the locus of the circle diagram will be like this if resistance is varied. If you now keep a fixed branch here, like this here there is no variation neither of this resistance nor of this reactance. So, this current is this I 2 dash with respect, but this is in parallel with the supply voltage.

This fixed branch is in parallel with this variable resistance branch, then the total current drawn from the supply will be nothing, but this fixed current I naught then this current is not I 2 dashed. So, that the current drawn from the supply is this one that is the idea I mean fixed current plus the reflected current and let us go and then you will understand.

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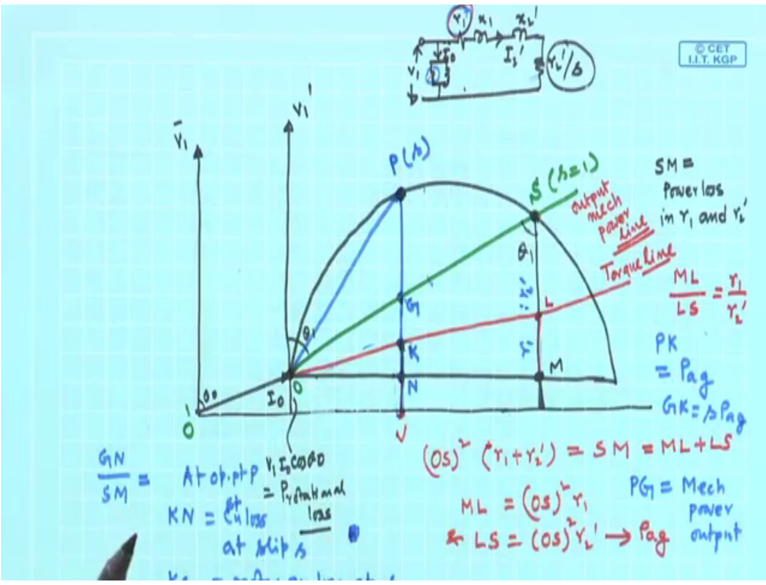

So, suppose this is your v 1 the supply voltage whether, this is your v 1. First of all v dash equal to 0, that r 2 by S is open current drawn is only I naught that is the no load current. Suppose that is I naught and I naught plus I 2 dashed voltage applied to this parallel branch, to this branch is also v 1. So, this current tip of this current facer I 2 dashed it will lie on the perimeter of the circle.

So, here I draw that that one, this is v 1 by the total reactance of this parallel branch maybe x 1 plus x 2 dashed v 1 by and I will vary the resistance and this is called the no load power factor angle theta naught. You recall that S equal to 0 point is this point is not because resistance is infinite then variable resistance. Then power drawn from the supply will be v 1 I naught cos theta naught.

So, this length this separation whatever is this length this is v 1 I naught cos theta naught, it represents the no load power loss or rotational loss because s is 0 that parallel branch this side does not take any current all the power will be consumed here, that is the rotational loss taken together ok.

So, this is equal to P rotational loss and as I told you earlier it does not depend upon at what slip the machine is operating. Because induction motor is practically constant speed motor. Friction loss change we neglect, flux change we neglect a little bit of change of flux will take place so this is constant ok. Now here also there will be two situations I will first draw a line here standstill condition s equal to 1, similar to the previous one; mind you did this current that is O s let this point be called O this is some O dashed.

So, this current the power factor of that parallel branch if you draw v 1 same voltage is applied to the parallel branch I can also draw v 1 dashed here to get I 2 dashed, locus of I 2 dashed is this to this are fixed current is added and if you join from O dashed to s which I am not joining to indicate the total current drawn from the supply it will only complicate the matter i mean the diagram will be very much with so, many lines ok. So, O s is I 2 dashed.

Now drop a perpendicular the way I the exactly the same step. So, I draw a line here of which this length I know it is the rotational loss, what is the total input power? Total input power is v 1 into O dashed s this current into cosine of this one is nothing, but this projection only.

So, this total length is this that is the total input power of which I have subtracted this rotational loss. Then the remaining power let us first ask ourselves what did remaining power is going, this time I have not neglected stator copper loss. So, there will be stator copper loss, then there will be rotor copper loss, then there will be the mechanical power output these are the three things. So, let this point be M ok.

So, v 1 into if you call this angle to be theta 1 this will be also theta 1 in the same way. So, S M is equal to what? SM can be thought of as the air gap power or not? Not air gap power, SM is equal to power loss in r 1 and r 2 dashed.

Let me draw the equivalent circuit in a small manner so that I can always refer, r 1 x 1 this is x 2 dashed and this is r 2 dashed by s and this is v 1, this is this current is I am calling I 2 dashed and this is the parallel branch which is I naught I have shown. So, here the power loss will be r 1 as well as r 2 dashed by s, power in this is the air gap power therefore, out of this total power SM; SM is the total power between these two points. If I subtract the power loss because of stated resistance then I will get the air gap power. Now, how to do that?

What I will do? I will this length SM I will divide into segment such that suppose this point let me call L such that ML by LS is r 1 by r 2 dashed. Suppose I know the value of the resistances so in this ratio I will divide this line and then I will join this point also, I will be joining this point. So, total input power to this branch total input power is OS square this length square into r 1 plus r 2 dashed and that is equal to SM because there is no mechanical power output at slip equal to 1 and I have divided this line in the ratio r 1 is to r 2 dashed.

Therefore, this is nothing, but ML plus LS, therefore, ML since it is proportional to r 2 in fact, this is so ML must be equal to OS squared into r 1 and LS is equal to OS square into r 2 dashed, that is this length then will represents the stator copper loss and this will represent the rotor copper loss and output mechanical power is 0, this is what all happens at slip equal to 1 and there is no output mechanical power.

Which length here represents the air gap power? The length SL is not SL is the power in this r 2 dashed by s; s happens to be 1. So, rotor copper loss and air gap power are same one and the same at s equal to 0. Therefore, this length LS also happens to be your Pag and what is rotor copper loss? 1 into Pag s equal to 1 and there the story ends.

Now, I will take a general operating point for example, here point P and this slip value is s. Similarly you drop a perpendicular here, now I will draw a perpendicular and this point of intersection let us mark say G this is KP GK and this point is say N. Here this length is of course, that fixed rotational loss that happens in this circuit parallel branch the input power is PN and there is this power K N, K G let us try to understand what this KN and KG means that I must show.

Now since it is so what is the current drawn that I 2 dashed; I 2 dashed is here is not OP square is I 2 dashed squared. Therefore, you can easily see that considering this circuit, that I mean this triangles; this triangle and this triangle they are similar this two are parallel is not.

Therefore you can easily see or show that this length will also represent copper loss at slip s in the stator and this will be the copper loss at slip s in the rotor got the point because you can always find out this ratios LM consider this triangle; this triangle and this triangle. For example, L K N or say the this one a say G K G N, this is interesting G N divided by SM GN by SM, it will be equal to OS by OG OS by OG and then this OG and OP can be deleted and this KN can be shown to be equal to at operating point P KN will be copper loss because I have divided this line in this ratio.

So, KN will be copper loss stator copper loss at slip s and KG will be the rotor copper loss at slip s at operating point P ok. So, this is the thing, this is that s equal to 1 that is stand still condition and this is when the machine is operating at slip s. Now when it is operating at any slip s total input power is of course, this length starting from P to this then you subtract this you get the power which is going inside this circuit of which this is stator copper loss, this is rotor copper loss.

Therefore, the length PK must be your Pag, PK this one must be your air gap power because total input power is this from which I have subtracted this power from which I have subtracted this power then the remaining power is going to the rotor and that is the air gap power. So, PK is equal to air gap power and then I know GK is also the rotor copper loss so GK must be s into Pag rotor copper loss.

And therefore, I will say PG then will be the mechanical power output and I will go to the extent to say that this is the net mechanical power output because rotational loss I have already taken into account by this length, that is the whole idea. Therefore, this will be so air gap power is the interception between any point on the perimeter and this red line air gap power.

Output power is PG that is these depending upon where it is operating, therefore, we say that did this line we say it is called torque line and this line is the output mechanical power line. Therefore, slip equal to 1 this line OS is always mechanical power output line we got earlier also, in earlier case when it was a simplified diagram if you recall; this is your output power line where is torque line torque line here was the diameter itself.

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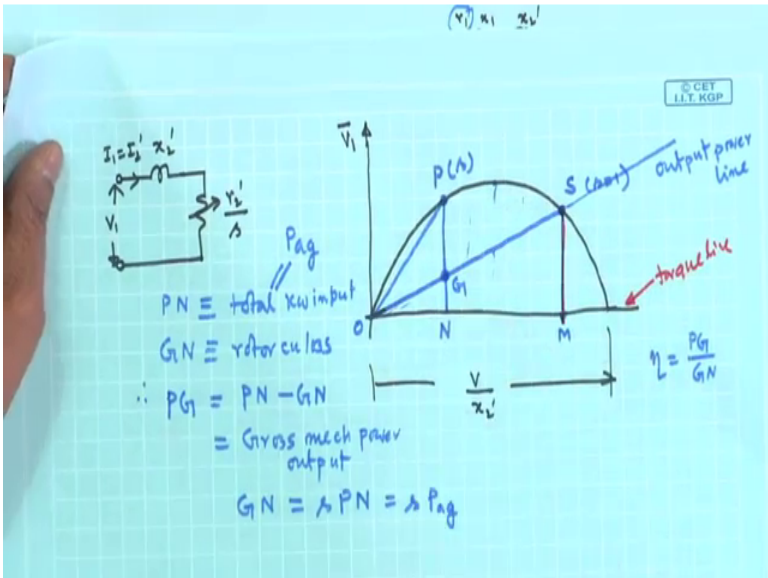

Because this is the air gap power so from whichever line you record this air gap power is called the torque line, but here it is tilted because of the stator copper loss and therefore, you can if you divide this SM length in the ratio stator resistance is to rotor resistance reflected values join these points for any operating point it will intersect that SK, then KN also represents the stator copper loss this intercepts will all represent stator copper loss, these intercepts will all represents rotor copper loss.

This whole length from P to up to this point say U whole power is the input power, this power is the power loss here fixed. Then this power is the power loss here stator copper loss, the remaining power that is K to P must be the air gap power of which GK will be the rotor copper loss that will be s times KP that is what all I have to say. Therefore, see the equivalent circuit in this form can be translated into a nice circle diagram of a slip ring induction motor.

Now I will tell if time permits today, otherwise next class that this equivalent circuit I mean the circle diagram can be just drawn by taking some two three readings that I will discuss, but before that I will try to tell you that because of the presence of r 1 x 1 earlier case to fix up this slip line was very simple what I am supposed to do? That is machine is running at slip 0.08 find out its output power input power things like that. Then what I have to do here? Here also I have not drawn any other slip line I have to at least calculate once, what is this theta? Fix up the operating point then tell everything.

Similarly, here coming how do I fix up the operating point, suppose I say slip is equal to 0.039, then what I have to do? Ok you will ask for the parameters value calculate tan inverse of that to fix up the operating point you know and then once you fix up that is fine, but there is a nice way of tackling that issue that is everything will be really graphical that thing I will tell you now, that is called to draw slip lines added to this diagram is called a slip line. This is also very interesting, that is given a motor you draw the circular diagram along with its slip lines.

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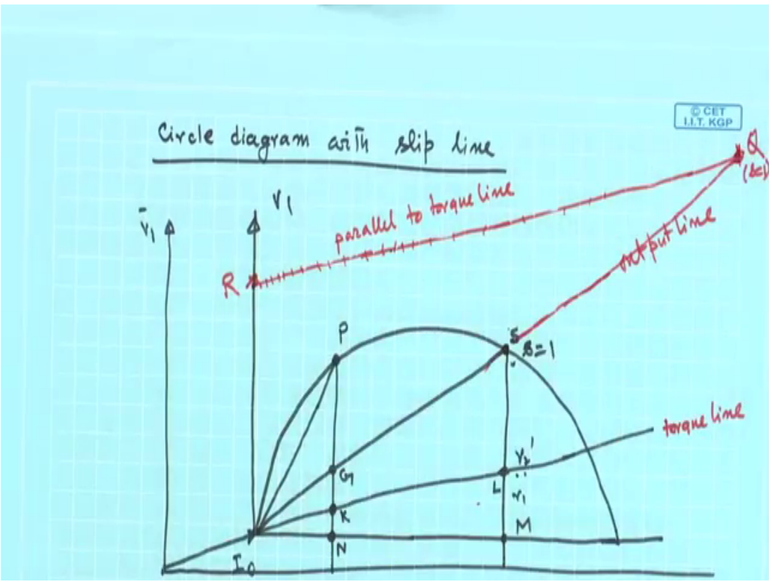

So, circle diagram with slip line. So, what is the thing? This is the thing this is supply voltage v 1, this is your no load current I naught and here is that parallel branch where r 2 pi s stays I will draw a bigger one and this is the circle, any point I 2 dashed this current will be I 2 dashed ok.

So, first is s equal to 1 point suppose this point s equal to 1 stand still operating point and you also draw a horizontal here, mind you this voltage axis is also here that is why it is I 2 dashed. So, you draw this line s equal to 1 and then as usual drop a perpendicular like this and this vertical lines gives you powers in total is input power, this length will give you stator copper loss rotor copper loss output mechanical power output mechanical power is 0.

Therefore I have divided these in the ratio it will be all the stator copper loss and rotor copper loss. So, in the ratio r 1 is to r 2 dashed I have divided and joined this line, the earlier diagram only I am drawing so this is capital S and this point is say I will not take much time quickly I will go. So, this is S, this point is suppose L and this point is suppose M and then any operating point it will be this will be the thing this is P and drop a perpendicular and let this point be called G and K and N and I know that that is what I explained.

Now, what I am telling first at least this much time is left I will tell what a slip line is and this line is called the torque line and this line is called the output line, what you do? You take any point; any point R on v 1 axis and draw a line parallel to the torque line that is here, this line you draw parallel to the torque line this is parallel to torque line. And then extend this line output line such that it intersects this point at some point Q; this R was arbitrarily chosen ok.

So, it intersects Q then what I am telling listen carefully, what I will do that proof will do later. This RQ say it is s equal to 0, this is s equal to 1, this whole length is s equal to 1. Then I will make my own scaling I will divide it 0.01, 0.02, 0.03 this is corresponds to s equal to 1, that is what it is. I will make a scale how to prove that? That is besides the point right.

Now what I am telling; what I am telling if such a line is given then to fix up the operating point if somebody says machine is operating at 0.04 slip, what I will go there? I will go here and 0.04, I will find out and join this point with that and then the wherever it cuts here that becomes the operating point; are you getting? The virtue of the slip line lies there and we will discuss it in the next class.

Thank you.