Electrical Machines - II
Prof. Tapas Kumar Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 39
Slip: Its Importance and Range for Motor Operation

Welcome. So, we were discussing about induction motors. Let us try forget, I will now, till now I have not given any name of the books, but it is now time to at least tell you about one book, which is very good and later I will add many other books whenever necessary.

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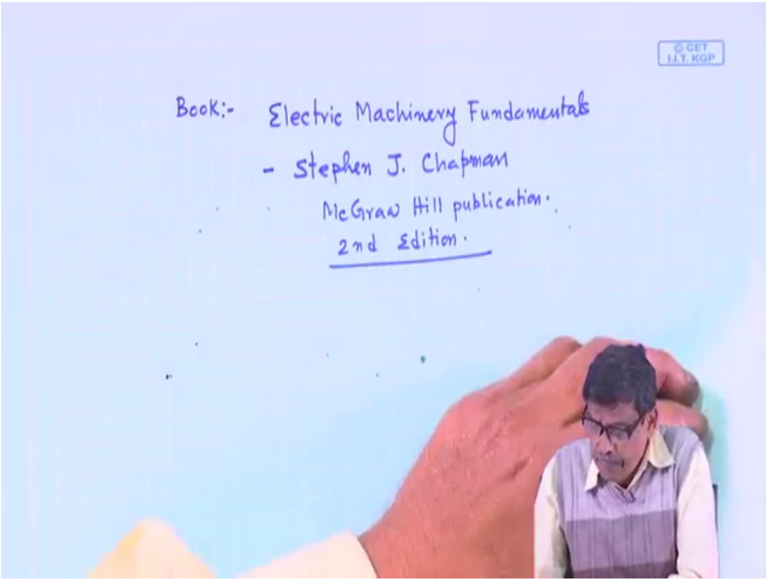

The name of the book is, book this you note down, it is like this Electric Machinery Fundamentals; title of the book is Electric Machinery Fundamentals and it is written by author is Stephen J. Chapman. It is McGraw Hill publication, McGraw Hill. Low priced editions are also available, most probably and this book I am talking I have a copy which is 2nd edition.

So, maybe later editions also we will do. So, this book in fact, in my last 4-5 lectures I have referred to this particular book that is B S B R B net expression of the torque, which is B R cross B S. Those things are very nicely dealt with in this book and you may please go through that book. Other books name as and when it is necessary I will tell you.

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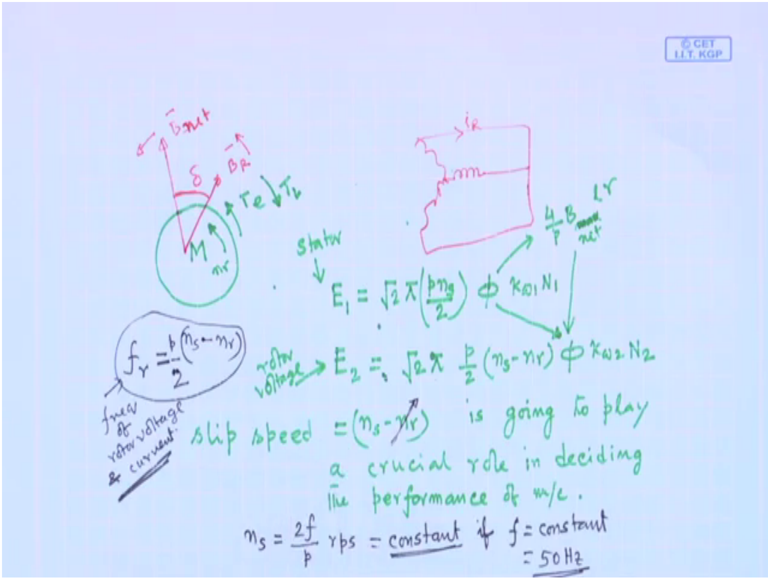

Now, coming to the discussion we are having that we were doing this light last time and I told you this is the induced voltage per phase and I was telling a very important point. It is the difference of the speed of the stator field or the net field and the rotor speed. This difference is very important, because that will decide essentially the magnitude of the voltage. Hence, the current in the rotor circuit and this difference in speed is called slip speed.

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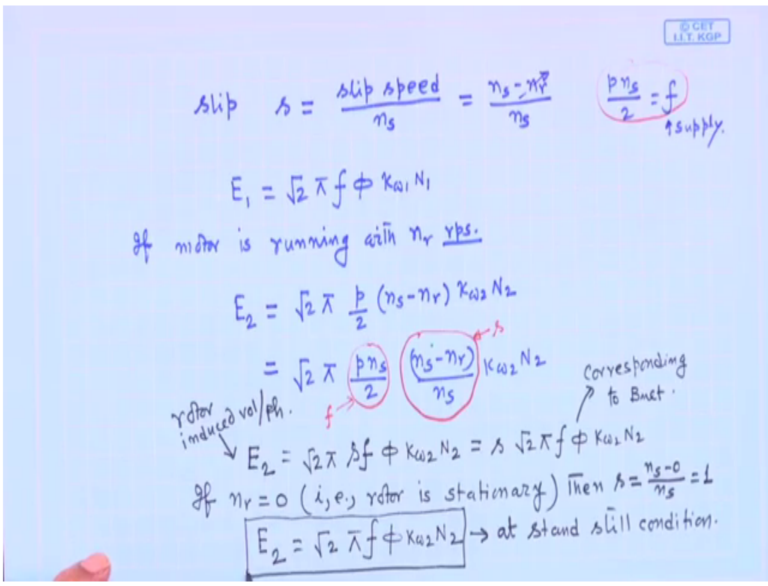

And not only that I will also define now this a term called slip, which is the slip speed divided by n s; that is how much is the difference in this speed as a percentage of n s is not it, I mean per unit values of n s. And in fact, I will show you right now that this term if you define it is this term instead of carrying on within the expression n s minus n r. This s comes so nicely, so slip at which the motor is running is nothing, but slip speed divided by synchronous speed of the stator field, which is constant and this may vary; therefore, slip may vary ok.

For example E 1 of course, E 1 does not change root 2 pi, this is f only p n s by 2, p n s by 2 is f supply frequency. This is supply root 2 pi f flux per pole due to net field into K w 1 N 1. If motor is running with n r rps then induced voltage in the rotor we have seen it will be equal to root 2 pi p by 2 n s minus n r into K w 2 into N 2. Now, this expression what I do I multiply with n s and divide by n s. So, that it will become p n s by 2 into n s minus n r divided by n s into K w 2 N 2 and we have defined this term as s slip and this is already known to be supply frequency this one f s. So, this expression then becomes equal to root 2 pi s f phi K w 2 into N 2 or people write it like this s root 2 pi f phi K w 2 N 2 and phi, do not forget corresponding to B net, this is the thing.

So, this is rotor voltage induced voltage per phase; rotor induced voltage per phase is this quantity. A special case is when the rotor is stationary ok, if n r equal to 0 that is rotor is stationary condition then s equal to n s minus 0 by n s which is obvious equal to 1, slip is then 1 and if slip is 1 the rotor induced voltage per phase is root 2 pi f phi K w 2 N 2 that is at people say it like this at standstill condition, at standstill condition. So, put s equal to 1. So, you see the importance of s, s comes in handy in expressing several things. For example, induced voltage in the rotor, which is understand still condition; E 2 here you should write s equal to 1 and here it is induced voltage when the rotor is running with a slip s. So, often the rotor speed is not directly expressed they tell machine is running with a slip 0.05; it means that n s minus n r by n s is 0.05 ok.

So, telling rotor speed and telling slip is eventually one and the same thing; you are trying to communicate at what speed the rotor is running. Only thing is while calculating slip which is equal to this quantity do not mix up with electrical and mechanical speeds. If it is mechanical, let all be mechanical. If n s n r are in rpm, let all of them be rpm or all of them, let be in rps or in electrical speeds everything you express. So, that is the whole idea.

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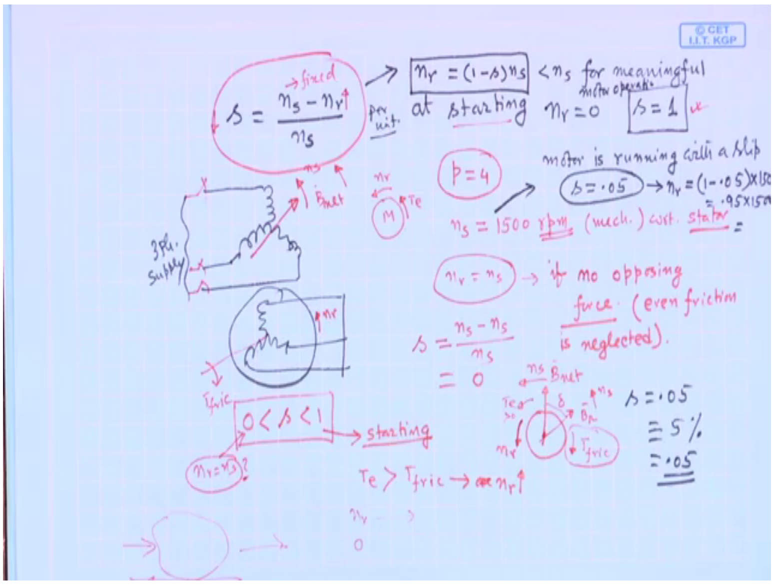

So, you see the slip then comes here and there ok. This is one thing which is very handy with slip calculation [FL]. Slip is n s minus n r by n s [FL] at these states. So, we can also say at starting of the machine when you are switching on this, apply with rotor circuit closed, then at starting s equal to n r equal to 0 motor is yet to start; so, at starting also s equal to 1. Now the question is, what is the range of s for motor operation [FL]. For that that we do not have to do any mathematics, but I will tell it like this; suppose you have an induction motor, I will sometimes draw like this, do not know it is immaterial.

We have understood, it should need not be drawn horizontal, just I have drawn. So, these are the three phase supply and what I have, and this is suppose the rotor and these three terminals are shorted like this and I have energized with three phase supply. And I know with proper phase sequence I can create a with rotor closed ultimately it is B net which is moving or p s, which is moving with synchronous speed n s with respect to a stationary observer like that and rotor is yet to start. So, at that time, at the point of starting when you close this switch n r equal to 0 at t equal to 0 plus also speed is 0; that is why n r equal to 0 and slip is 1 like this [FL].

Then we have learnt motor will start rotating in which direction, it will rotate if your field, stator field or B net is moving in this direction rotor will start moving n r. So, n s minus 0, it has started then speed will expected to grow up, speed will become 10 rpm, 15 rpm and so on like that and let us do this exercise. Suppose p equal to 4 number of poles then I know n s is equal to 1500 rpm. I gave you a table to 2 f by p etcetera you, do you get and all our mechanical speed and with respect to stator. It will move and it will move in the anti clockwise direction, as I have shown the phase sequence I have chosen that way. So, it moves then rotor starts, also moving in that direction and as it moves the value of slip which is n s minus n r, n r is increasing and slip value will decrease, because n s is fixed; therefore, slip value will decrease.

So, it will become, it was 1, it will become 0.9 0.8 like that and it will go on accelerating. Now what will be the final fate of this motor, that let us talk about that without doing any mathematics and we can easily do that. Now as the rotor picks up speed, a time will come when n s rotor approaches this 1500 rpm and if rotor speed is still below 1500 rpm, but close to 1500 rpm does not matter. So long there is a relative velocity, there will be induced voltage and induced current and the moment there is the induced current, there is B R and B net to give you torque delta is not.

So, rotor will then accelerate whether the that torque value is changing with time or not, but it is a positive torque. Recall this diagram for a motor if this is T e your direction of rotation is also in the same direction. Now the question is, let us assume there is no opposing torque absolutely on the shaft, no friction, no air friction, it is very ideal situation, but let us assume, there is no opposing torque then what the rotor is going to do. At what speed it will settle down.

Then there is no problem, speed will go on increasing, a time will come when n r will become equal to n s increasing and it will become equal to n s. It is right at that point the moment, the rotor field reaches n s, slip will become 0. And if slip is 0, I am sure about this thing that there will be no rotor induced voltage, there will be no rotor current. Although the rotor circuit is closed, but it is devoid of any voltage induced. Therefore, there cannot be any current and there is no b r, no rotor field, all the thing is present is b s which itself is B net at that time.

Therefore no torque will be developed and rotor will run n r, n r equal to n s if no opposing force, if no opposing force that is even friction is neglected then rotor will run also at 1500 rpm and in a frictionless environment. You do not require any torque to be applied, it will continue to run, but that is an ideal situation. Now, so, so in at the best at most n r could be equal to n s. Therefore, slip at that time n s minus n s by n s is equal to 0. Therefore, the range of slip for motoring operation is from 0 to 1, this is the range where s equal to 1, is a very real thing. No idea, nothing s equal to 1 exists, so when you switch on this apply. This corresponds to starting.

So, range of values of slip, it can assume any value between 0 to 1 and this corresponds to n r equal to n s which is of course, a doubtful proposition, because no machine is frictionless ok; therefore, but nonetheless these two values of speed define the range of the value of slip, we now know clear [FL]. Now, let us be realistic. Suppose on the rotor there is a friction present. So, you energize the rotor, stator field is there; B net or stator field moving with n s, it is there. And so if this is the direction of the field rotor starts moving like this with n r speed, n r is now a function of time, it will gradually pick up speed, but the point is, it is moving and slip value is decreasing induced voltage decreases, current decreases, but now so long current is there, there will be B R, all present and there will be a definite delta.

Now, as it does, so like that it evolves with time, but nonetheless angle between them remain same. Both of them are running at synchronous speed, no matter what is the value of n r; that is another interesting observation we have seen earlier. So, it does like that with time and I am now telling there is an opposing torque T friction this, this is the added thing. So, long we neglected opposing torque only T friction is present. Then what the, what the rotor is going to do and what it will do ok, then rotor accelerates. First of all rotor will accelerate, start accelerating if your starting torque at s equal to 1 is greater than T friction, like you have a very big rock, you push it will not move. It means that the frictional force which is already present here you have to work on that friction torque. And frictional value of the torque of course, depends upon mg into mu something like that. Therefore, unless you apply this much of force it will not start moving.

So, similar thing here ok, you energize this apply and there is some opposing torque, frictional torque acting in the opposite direction and you know there is a stator field, there is a rotor field, the circuit is closed, electromagnetic torque is there, but this electromagnetic torque must be greater than T friction, so that the drama begins. I mean rotor starts moving otherwise what. So, we assume that friction is so small enough starting torque is developed and it will accelerate, and so long this electromagnetic torque is greater than T friction, acceleration continues n r goes on increasing you know, but as the n r goes on increasing I know one thing induced voltage in the rotor decreases induced current in the rotor decreases B R decreases.

Therefore electromagnetic torque which is accelerating it will decrease, but nonetheless it will accelerate so long that positive torque T e is developed. T e is in this direction and that decides the direction of rotation. So, long this T greater than 0 it will go on accelerating. So, in this way as it does, a time will come T decreasing T was greater than T friction when you started at T equal to 0, but with time T is decreasing and soon a time will come when T e will be equal to T friction.

Earlier there was no opposing force, so it went on increasing speed and n r became finally, eventually equal to n s, but now it is not like that, electromagnetic torque is there. I know it is decreasing initially, it must be greater than T friction, but as speed increases, relative speed decreases induced voltage in the rotor decreases, induced current in the rotor decreases, electromagnetic torque value itself should decrease, and finally, it will so happen that a time will come after reaching certain speed. At a certain speed you will find oh T equal to T friction and then the rotor will start moving at that speed which will make enough relative speed to cause a development of electromagnetic torque which is equal to T friction is that, it is as simple as that.

Therefore, it is not my botheration whatever opposing torque is there, machine will very faithfully do that. Therefore, rotor will settle down to a final speed when an opposing torque is there at a speed which is less than n s and enough to produce an electromagnetic torque which will be equal to the opposing frictional torque and everything is settled. Therefore, it looks like that slip, in terms of speed I will tell n r at starting it was 0 n r will increase and we will eventually settle down rotor speed. You can write it down, rotor speed will eventually settle down to that that value which is less than n s, it has to be such that enough torque the motor can develop to balance the opposing torque, it is at that speed it will settle down ok.

Therefore the speed I told you can be expressed in terms of slip, either you tell slip or speed you know down that these equations can be also written as. This is also an useful way of writing this equation n r is equal to 1 minus s into n s, this is very useful is not when s equal to 1. It will be 0 rotor speed, but rotor in a practical machine cannot run at n s, because in the presence of an opposing torque before reaching n s, it has to settle down to some lower rpm, lower than n r.

So, n r is this and it will be always less than n s for meaningful motor operation, for meaningful motor operation ok. So, suppose coming to this, this exercise let me do n s equal to 1500 rpm for a 4 pole machine. Instead of telling the speed people say that motor is running with a slip is equal to s equal to 0.05. As I told you when somebody says slip he is indirectly tell me about this speed how, because then if I want to calculate the rotor speed I will say oh n r is 1 minus 0.05 into n s which is 1500, n r equal to 1 minus 0.05 which is equal to 0.95 into 1500 rpm, how much. Anyway some rpm you will get very close to 1500, but less than 1500.

Therefore telling the rpm is one direct way of telling the rpm of the machine, but often people will say slip value and slip value this s equal to point 0.05, he sometimes also tell a people like this machine is running with a percentage, the slip is after all per unit, you know per unit. So, 5 percent means s is equal to 0.05 in absolute term, this also you should know.

So, in today's class what I have done is this, I have defined one important term called slip and told you about what is the range of the slip value for motoring operation. It will be between 0 to 1 can slip be equal to 0 ok, ideal condition it is when there is no opposing toque or opposing force then only a rotor can run at n r equal to n s at starting. Of course, a slip value is always 1 and slip may lie between 0 to 1, any value it looks like and then I tell to you what happens when there is opposing force present.

For example I did not think like frictional torque; of course, motor will start moving if you are starting torque developed by the machine is greater than T friction, motor will accelerate, but this time it will not eventually go to synchronous speed. Because, there will exist some speed which will cause enough relative value of n s minus n r to develop electromagnetic torque which will match the T friction and machine will be quite happy to run at a speed less than synchronous speed, but T equal to T friction. So, with this I stop today, we will continue this discussion next time.

Thank you.