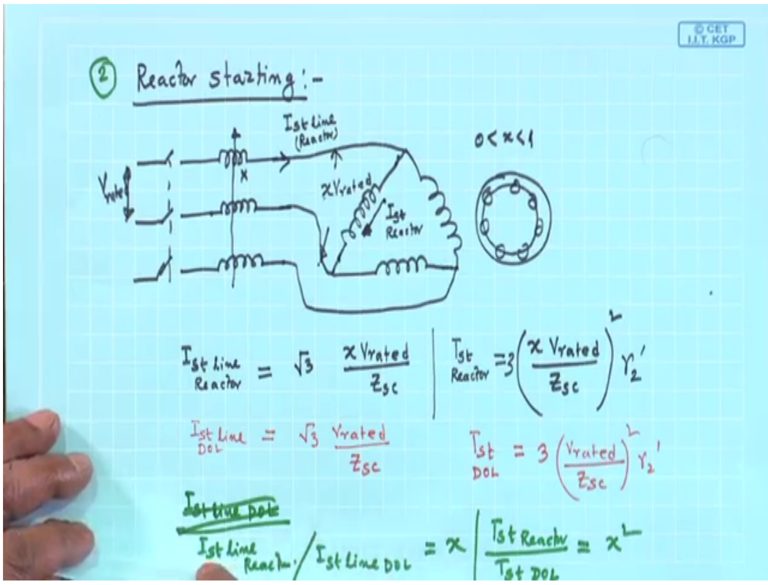
Electrical Machines – II
Prof. Tapas Kumar Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 60
Introduction to Speed Control

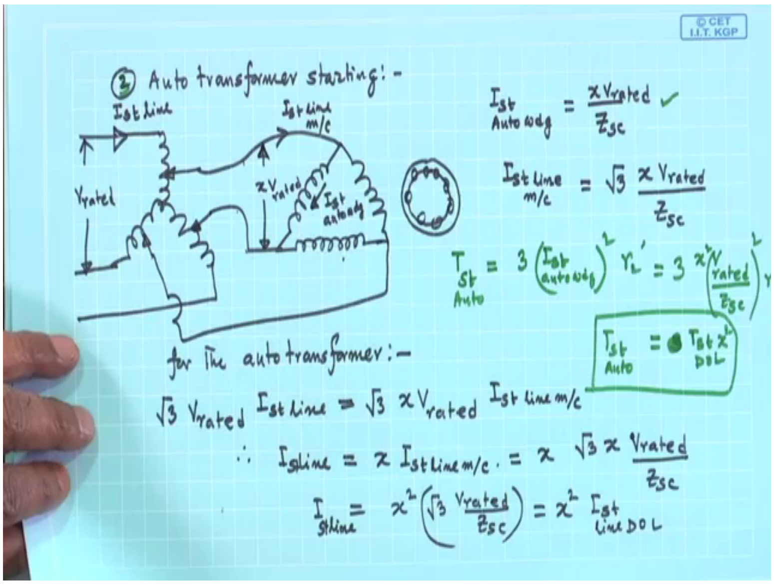
Welcome. So, we were discussing about the problem of starting large induction motor from direct full voltage supply. And then we the solutions where that for wound-rotor motor you better connect a resistance in the rotor circuit terminals are available, but; however, for cage induction motor which is very popular and widely used that thing is not possible. So, you have to adopt a reduced voltage starting of which we have discussed reactor starting you have to connect a reactance in line with a series and then auto transformer, you have to connect an auto transformer at the very beginning this was reactor starting.

(Refer Slide Time: 01:07)



Only thing I leave it to you to try to understand even if it is wound-rotor induction motor you could apply it; I mean no problem if it is wound-rotor induction motor rotor shorted you could adopt any of these method, but since wound-rotor motor that facility is there you can do like this, similarly auto transformer starting.

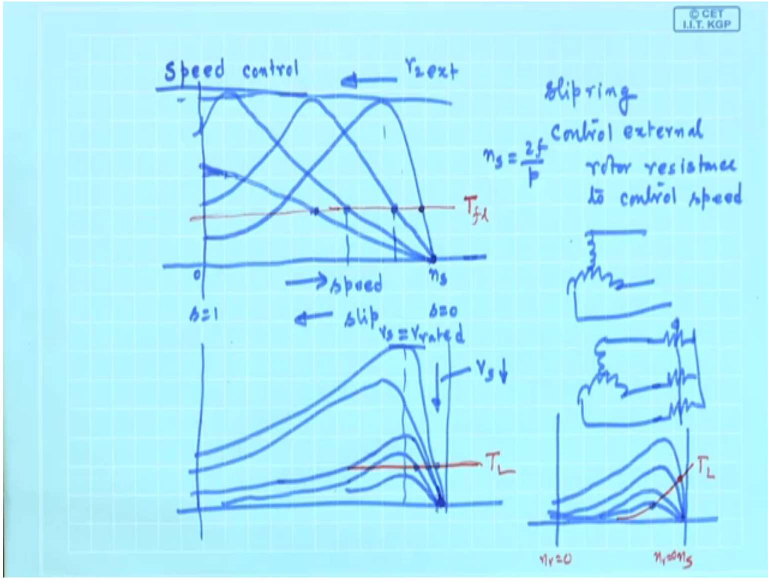
(Refer Slide Time: 01:39)



But, you have to see your motor operation now depends on another equipment of same rating. So, cost is pretty high because you have to of course, go up to this point when the motor will be running after machine has started picked up speed, it has got close to synchronous speed. Then, of course, by doing a switching here you can give the supply corresponding to rated voltage that arrangement can be done. But, only thing is these things can be avoided and a start delta starter can be used provided that motor is meant for delta connected the rated condition operation; otherwise it is not possible and not only that all the terminals of the stator must be brought out.

We will later see that nowadays the induction motor can be very soft started by using electronic invertors. We will that we I will also tell while discussing the speed control of induction motor. So, first speed control of induction motor various methods which were earlier used, no point in discussing in detail, but I will give you definitely the idea.

(Refer Slide Time: 03:16)



For example, so, next topic is speed control see for any motor three things are important one is the starting how do you start the motor always any motor full voltage if you apply at the time of starting it draws large current; be it DC motor or AC motors like that; so some starting arrangement is to be made. Similarly, how the speed of the motor can be controlled, ok; this is another and third one is breaking electrical breaking that is if you want to bring a already running machine to come to stop quickly what electrical arrangement can be made or done?

So, about the speed control the problem is clear because suppose you have an induction motor whose torque slip characteristics is suppose like this. And this side is speed you understand that and this is slip I have for the first time drawn it like this reversed, but it does not matter this is the starting torque. So, speed is 0 here and speed is n s here and slip you know s is 0 here, s is 1 here. So, anyway this is the induction motor speed and motor operates in this table zone this is almost a linear portion and we have discussed that.

Suppose, there is a load torque, full load torque it will be in between this about 5 percent; this value I told you about 10 percent for estimation. So, suppose this is full load torque and this full load torque I want to supply at various speeds. Mind you, from no load in no load frictional torque it was operating here, full load it has come here and there is a change in speed, but this is not called speed control. It is speed regulation; inherent speed regulation of the motor. So, it must run at lesser speed so as to develop more induced voltage in the rotor more current etcetera more power.

So, this is speed regulation from no load speed to full load speed the by the term speed control I mean that if this is the load torque can this load torque can be supplied at various other speeds? Like this speed is close to synchronous, can I make it run at a speed n s by 2, close to that? Then it is speed control ok, same load torque I am supplying. The answer is yes, whatever we have learnt so far, it can be done. For example, if it is slip ring induction motor it can be only done with a slip ring induction motor controlled rotor resistance control external rotor resistance rotor resistance to control speed.

You know a if you vary the rotor resistance we know this speed torque characteristics will shift it will be like this r 2 increasing this way r 2 external increasing. And you can get a from the same torque slip characteristics you can get a thing like that. Why not more like this different values you can get.

And, you can easily see that is in the rotor of the machine stator supply you give and on the rotor slip ring and brush I am not drawing. You are connecting the resistance and varying this resistance and you will find it may operate then at this speed, it may then operate at this speed, it may then operate if this load torque is like this, it will operate here; stable zones. These are stable zones, mind you only thing you have extended the rotor resistance.

Therefore, smooth variation of the speed of the motor can be achieved provided you increase this rotor resistance and down to a very low speed. So, I was telling the other day if on the name plate of the rating of the machine some speed is written that is if on the nameplate of the rating of the machine some speed is written that is the full load speed ok, that is this speed.

However, if it is needed you can run it at much lower speed in this stable zone for various reasons speed control is required you can understand. But, only point is only objection to this method is there will be excessive power loss because of the presence of the external resistance in the rotor circuit and this resistance I am not using only for the starting purpose I want to control the speed. So, resistance must be present in the rotor circuit as well and therefore, rotor current will flow as you load the machine T fl is there;

therefore, there will be huge copper loss in the rotor and efficiency of the whole system is down.

So, although a smooth speed control is possible it is not very much used nowadays it is not used at all I am telling you, but the idea is like this. Similarly, earlier days people use to also tell that a speed control by controlling the supply voltage. I will control the supply voltage and hence get different operating speed. For example, this is the inherent torque slip characteristics with V rated voltage and this is the suppose the load torque is here, you reduce the voltage and if you make the supply voltage half then the maximum torque will become one fourth.

So, it will be like this; the slip at which maximum torque occurs here in this case will remain same and therefore, it will become like this and it will become like this for V applied you are reducing. V supply is V rated, V supply your decreasing, various families of curve you will get and you will say it was running at the speed. Now, it will run here, it will run here like that. But, this is also a see over a very limited range, you can control the speed that is one thing and second thing is if the load torque is constant the game will be over if you further reduce the voltage machine will come to stop your motor will not be able to produce torque this way.

Perhaps still people say why they say is because of the fact if see I am drawing load torque constant demand this is the torque speed characteristics of the load in the redline I have drawn, but if the torque slip characteristics, it need not be the demand of the slip torque characteristics is like that. It could be this way suppose this is the load torque and this side mind you this is n s and this is n r equal to 0. If the load torque characteristics like this that is the load torque demand increases if you reduce the speed then this method may be able to sustain it will operate here, it will operate here that is the top demand that lesser voltages are lesser.

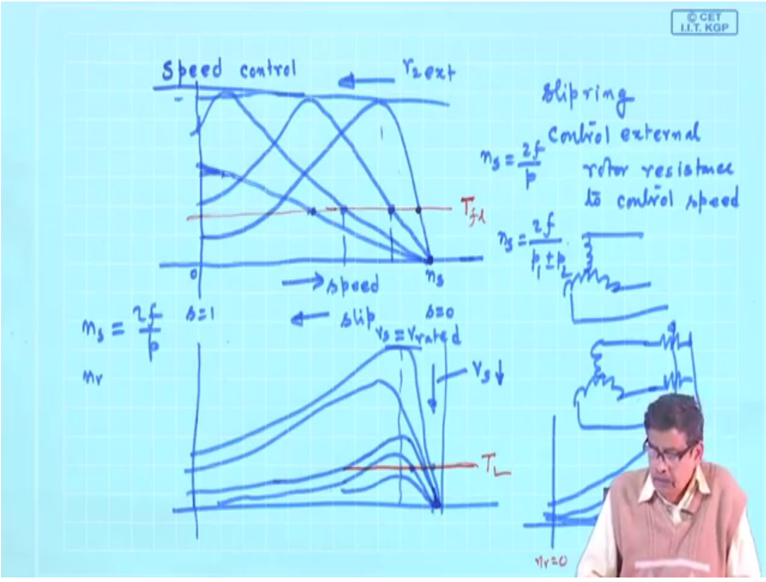
So, this although these speed will be very limited. It cannot be motor cannot be made to run at a very low rpm, these days are over. So, that is with slip ring induction motor. So, slip ring induction motor rotor resistance is one option, supply voltage variation may be applied both to slip ring and cage rotor and there were in earlier days methods I will just mention verbally and tell you the story.

Earlier days, because after all the synchronous speed decides the rotor speed 2f by p so, people use took have several stator windings or same stator windings connected for two-poles or four-poles by doing some external switching, are you getting? One day I was explaining to you, same three-phase winding it can be made to appear as a four-pole winding or a two-pole winding by interchanging the connections of the different phase groups or coils like that. In that case all the terminals are to be brought out from the machine.

And, then you want to operate as a two pole machine connect the terminals in this way if you want to operate at four pole machine connect the terminals that way, so many terminal, then externally connect, then give supply by doing that you can at best get two discrete speed. Suppose you are changing the connection of the stator coils whose terminals first of all you have brought out and made it connect to give you a two pole which corresponds to 3000 rpm and another for four pole which corresponds to 1500 rpm because motor after all will run at close to synchronous speed and below the synchronous speed; therefore, there were complexities.

Another thing was there where people used to take two induction motors which are mechanically coupled up to different number of poles separate machines is a p 1 poles another a p 2 poles and this motor could be connected in cascade, that is, the rotor of the first motor is used to supply this stator of the second motor. First motor should be a slip ring, second motor should be a cage it could be a cage and then those are nice interesting methods, no doubt.

(Refer Slide Time: 16:43)



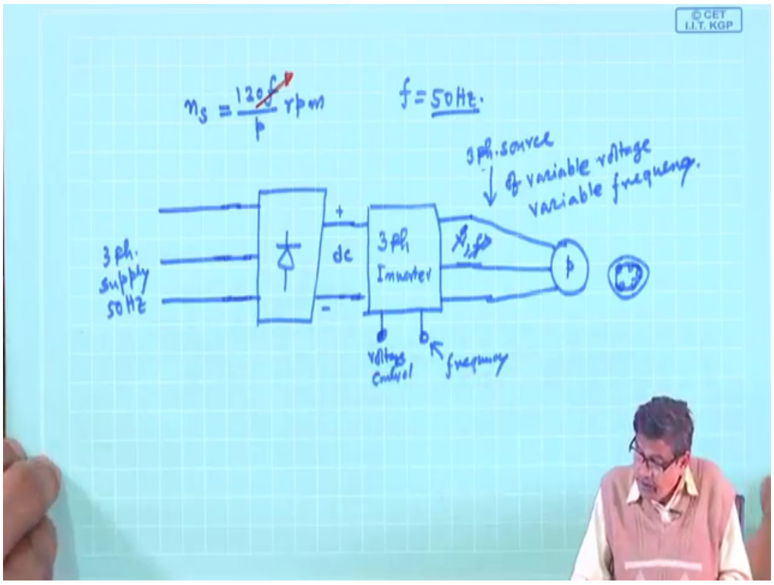
Then, you could generate a synchronous speed of 2f by p 1 plus minus p 2 etcetera; two machines you have to use and these two motors are coupled. It will the common mechanical load will be on the shaft of the motor so, by using pole changing method; a pole changing method [FL] the effective pole of the machine of the whole setup as you are changing.

So, perhaps 1 2 3 4 possible speeds are possible. One is 2f by p 1 do not connect the second machine, another is 2f by p 2 first machine do not connect another is connect these two machine in cascade that is rotor of the first machine is used to supply this stator of the second machine. And, depending upon the phase sequence of the supply of the second machine p 1 plus p 2 or p 1 minus p 2 will come. Discrete speeds you could get but, nowadays no point in telling. To control the speed of an induction motor you take another induction motor, not a good proposition in present day therefore, this we will not discuss although these are interesting whoever first suggested must be very I mean intelligent persons to do that.

The problems where elsewhere the problem of induction motor when you compare with DC motor in those days, induction motor requires a three-phase supply, three-phase supply is there and the supply frequency was fixed 50 hertz; you cannot do anything with that frequency earlier days. In case of DC motor you control the armature voltage, you control the field current by a simple rheostats smooth control of speed is possible. But, with frequency fixed for a given induction motor whose stator connection you do not want to change the synchronous speed is fixed 2f by p and rotor speed will be simply very close to n s at steady states that is all and therefore, induction motors where considered to be almost a constant speed motor.

People used to one question which was very common even 10 – 15 years back that interaction which motor is used? Series motor, DC series motor was the answer, ok. Nowadays also it is used, but the problem is nobody was talking about induction motor whether speed could be controlled at is with induction motor. We found whatever standard techniques where there these are either efficient inefficient techniques cannot be used or you require complicated winding terminals of the stators available to you and that too discrete speeds only smooth speed train, you want to move at various speeds you like starting from 0 speed to any speed you define.

(Refer Slide Time: 20:40)



So, so, nowadays so, the problem was because of there because the synchronous speed is the deciding factor which is 120 f by p in rpm and f was 50 Hertz constant. So, for a given machine synchronous speed is constant, hence it is rotor speed. Now, with the advent of power electronics inverters the that thing can be overcome because you can easily see to control n s why not control the supply frequency? Why you say only 50 Hertz is available and do not do anything else therefore, I must have a device which will, but my existing supply available at my doorstep or in the lab is 50 Hertz that is the mother supply, I cannot do anything with that.

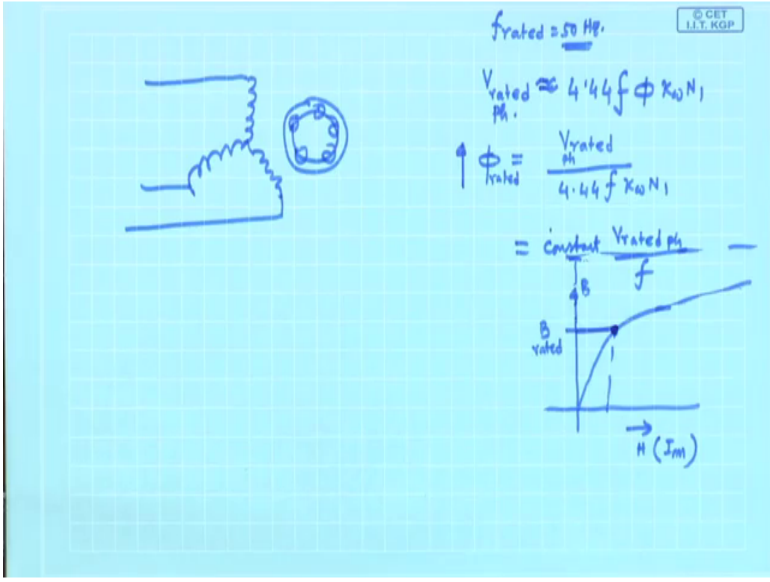
So, this so, in block diagram it will be like this. This is your three-phase supply, 50 Hertz is there and then motor I was connecting earlier, but now those days has gone. What you can do is this you first convert it to a DC supply use a rectifier get DC that I can do diode rectifiers, power diode rectifiers are available I will make it DC.

Then, whatever I will connect is a 3 phase inverter; inverter you know with fast acting switches like MOSFET, transistor switches. It will give out a 3 phase source here. And there should be controls by which it will give you a output balance three-phase voltage source of variable voltage, variable frequency I will just touch up on this idea; ideas are so nice that is why you must know. So, it is DC here, have a very smart inverter which will give you a variable voltage, variable frequency output maybe I am telling indicating it is suppose voltage control there will be a norm, there is a frequency control ok.

And, I can then have any voltage any frequency situation like this; if this thing is available and if this is your induction motor beat cage wound-rotor I do not mind now do not care rotar is cage suppose and variable voltage variable frequency supply, with that I will excide the machine. Then at least one thing is clear, ok, supply frequency can be controlled number of poles I will not touch the winding, no point the motor in cascade no. So, like that we will do and if frequency can be very smoothly controlled speed 2 will be controlled.

Before I talk let us try to see what is going to happen.

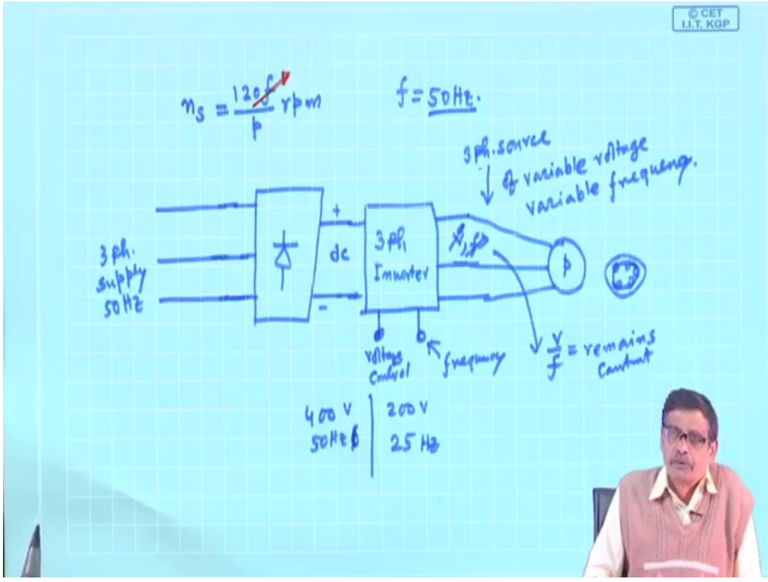
(Refer Slide Time: 24:54)



Suppose, you have an induction motor one thing of course, very important to understand is only this much here that is this is the stator, this is suppose the rotor. The motor has got a rated voltage and frequency and if rated voltage and frequency is there rated V rated. How it is related with frequency applied voltage because that leakage impedance drop is negligibly small if you assume. So, this is nothing, but 4.44 or root 2 pi f then phi into then K w into N 1 per phase voltage per phase rated voltage; this is the basic equation.

Suppose, somebody says I will and the rated frequency f rated is 50 hertz. Based on that rated voltage frequency there is some rated flux I can calculate of the motor and note that phi flux is V rated phase by 4.44 f and K w into N 1 now K w N 1 are constants they are not changed and here is this one. So, it is some constant into V rated phase by f.

(Refer Slide Time: 27:09)



Suppose, rated voltage is 400 volt 50 Hertz actual machine rating I suppose decide I will run it at 400 volt because inverters gives you variable voltage variable frequency I will adjust it to 400 volt and 25 volts I want to run it at half the rated speed. Suppose, what depending suppose p equal to 4 rated speed is 1500 rpm, 50 Hertz supply.

Now, suppose I say oh if it is so easy then apply rated voltage, but make frequency 25 Hertz it will give you 750 rpm you know or in between any frequency; reduced frequency 50 Hertz down to 25 Hertz it will give you smooth speeds of synchronous values, but the problem will be there. What is that? If you keep the voltage fixed and go on reducing the frequency; then the phi will go up, phi as you know it is 4 by p B max lr that this B max will go up.

And, the motors or transformers are designed if you look at the B-H curve of the machine which is not a straight line or it is whole range of operation. So, this is H or in other scale magnetizing current N I m by l something and this rated flux density corresponding to phi rated, this is B, this is B rated. It is selected at the knee point of the machine based on that it is decide. So, immediately I observed if I keep the voltage same and frequency half; the level of flux required this equation demands flux density should be should be twice like this and therefore, the current drawn will be very large.

And, in other words people say the motor will get saturated. So, saturation is to be avoided. So, how this can then be avoided? Do not control the inverter which is supplying the motor if you are wearing the frequency in the lower range. Make sure V by f this ratio remains constant, that is, if it is a 400 volt 50 Hertz machine Hertz if you want to run it at synchronous speed corresponding to 25 Hertz that is your intention, then applied voltage should be also made 200 volt. So, that flux level remains same, understood?

Therefore, it looks like that frequency supply frequency which is nowadays very easy to implement should be the keyword in controlling the speed of the induction motor. And also we will see that starting method we are using some auto transformer and reactor, those things also will not be needed when you have a variable voltage variable frequency supply. So, in the next class I will tell you about that, ok.

Thank you.