Electrical Machines – II
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Lecture – 61
Idea of VVVF Speed Control of Induction Motor

Welcome and we were discussing about the Speed Control of 3 phase Induction Motor, of which earlier days people used to adopt different methods. For example, if it is a wound rotor induction motor you can vary the speed by varying the rotor resistance or you could vary the supply voltage alone, that is you can only reduce the supply voltage from its rated value, then also speed control is possible, but over a very limited range.

And also if you adopt voltage control method, the pull out or maximum torque decrease drastically. And then there are methods also adopted in earlier days, that is the you can control the speed of the induction motor and they are very popular in those days. That is you have 2 sets of say stator windings; 1 set will give you suppose 4 pole other windings will not be used or other winding when it is used it gives you 2 poles and thereby you can get synchronous speeds of 2 values.

Apart from that of course, same winding can be used to create different number of poles in the ratio of 2 and you could control the speed of the induction motor. Another interesting method was that, that I just mentioned if time permits I will discuss that is you can control the speed of a induction motor, but in this case in this particular method, you do required 2 induction motors one of them must be a slip ring type.

So, what you do you supply the first you take the wound rotor induction motor, supply the stator of that induction motor with rated voltage frequency and then through the secondary that is the wound rotor type induction motor rotor terminals, you will get induced voltage of slip frequency. And then that voltage is used to energize the second induction motor which is cage type. And these two motors must be coupled and then you can get some 4 number of discrete speeds; one is corresponding to p 1 pole machine 2 f by p 1 another is 2 f by p 2 another is 2 f by p 1 plus p 2 another is 2 f by p 1 minus p 2.

And so, this was the thing, but I will just tell you qualitatively how the scenario has changed to control the speed of the induction motor because, the speed after all is decided by the synchronous speed of the rotating field which is nothing, but 2 f by p.

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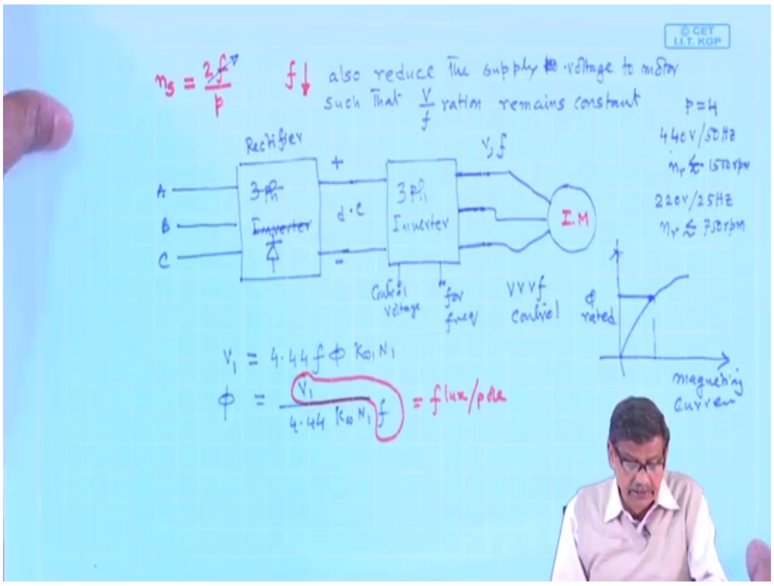

So, in earlier days people were thinking about changing the number of poles, but now a days what they do? They change this try to change the frequency of the supply. There by changing the synchronous speed hence the speed of the rotor of the motor. Now, the change in frequency is not very straight forward, but it is like this the block diagram I draw, that is you have got 3 phase supply here 3 phase supply and then you have got a 3 phase inverter. No first you have a rectifier, make the supply dc it is rectifier maybe diode bridge rectifier and this is your 3 phase supply A B C or R Y B.

Now, here you get dc and then this dc is fed to a 3 phase inverter 3 phase inverter. Inverter as you know changes your dc supply to a 3 phase supply balanced 3 phase supply of frequencies decided by the strategy you adopt in this inverter control circuit, that is frequency of this output of the inverter voltage both frequency as well as the magnitude of the voltage can be changed.

The idea is like this. So, you will have 2 control one control one control for voltage maybe another control maybe for frequency, and you at the output of the inverter it looks like you can generate any given voltage at any given frequency. Now this one is used to supply the stator winding of the induction motor. The point in my last class I was trying to tell the applied voltage to the motor per phase if it is V 1 rms value this we know it is 4.44 f flux per pole into K w 1 into N 1.

Now, this equation is interesting to note that this is 4.44 f K w into N 1 into f now this ratio look at other things being constant of the machine I cannot do anything and this is flux per pole. And the value of the flux per pole will be rated value, if you apply rated voltage and rated frequency. What is rated voltage and rated frequency? That is the nameplate rating of the induction machine.

Therefore that is called the rated flux therefore, I must say that in order to control the speed of this induction motor, if you vary the frequency downwards that is 50 hertz motor I will vary the frequency to 45 hertz 40 hertz. And, we will get different different synchronous speeds and I know that that will be the speed of the rotating field. And therefore, rotor cannot, but run as dictated by the synchronous speed of the machine very close to synchronous speed, but below it with some small value of slip.

Now, the question is if you keep the voltage fixed and go on decreasing the frequency what happens is this flux will rise and to develop that flux you will require more and more magnetizing current. And the bh curve tells me that if you reduce the frequency keeping the voltage constant, the machine may go into saturation because bh curve of the material after all is of this kind and the rated flux is at the generally at any point of the magnetic circuit.

So, as you change the and this is the magnetizing current. As you reduce the frequency along the if you make the frequency half you know flux will be doubled and current drawn will be very large. Maybe many times more than the rated current even of the induction motor and then we say saturation has taken place therefore, machine should not be worked and in saturated condition it unnecessarily draws very heavy magnetizing current.

In any case if the machine is supplied with some protection even under no load condition it will draw very large magnetizing current fuse will protect the motor that is the idea. Therefore, if you want to vary the frequency from its rated value and you want to decrease it in order to run it at lower and lower speed, there is a problem now.

So, constrain is or the if you want to reduce the frequency, also reduce also reduce the supply voltage. That is this voltage and this frequency also reduce the supply voltage supply to motor supply voltage to motor such that such that such that this V by f ratio this ratio remains constant remains constant then at least you assure machine will never go to saturation ok. And not only that rated flux will be preserved, suppose the machine rated voltage is 440 volt and 50 hertz.

If you want to run the machine and suppose p equal to 4 to give you concrete example, the speed of this machine when it is supplied like this it will be close to n r will be close to and less than 1500 rpm ok. Now what I will do I will apply 220 volt 25 hertz. So, that the ratio once again remain same as 2, but the synchronous speed because it depends only your frequency and number of poles of the machine it has become half. So, new rotor speed will be less than and close to 750 rpm that is the idea and this is true for any lower frequency.

As you decrease the frequency speed can be therefore, this control of course, I have shown independently you can make logic this that so, that you send supply voltage and frequency such that the V by f ratio remains constant understood. So, the idea is this that is you apply the voltage variable voltage, variable frequency it is often called variable voltage variable frequency control. Now, the question is how what about the top slip characteristics under this condition? If you recall we can easily do it for from the very involved equivalent circuit but let us try to get the idea from this equation.

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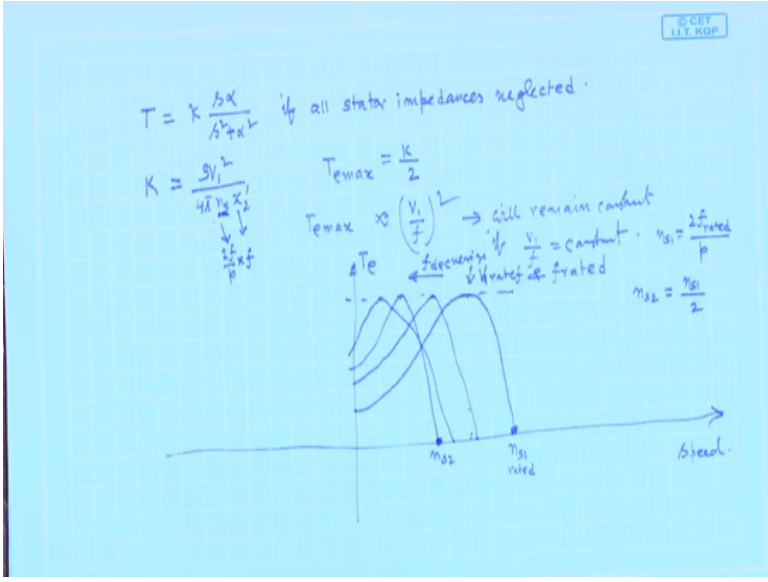

Just to get a firsthand experience how the speed will change. So, we know this is the expression of the torque if all stator impedance is neglected all stator impedance is neglected and mind you what is the value of K. K was some 3 V 1 square by 4 pi n s most probably like this x 2 dash K the constant value and also we noted that T e max T e max was equal to k by 2 now. So, this was the thing most probably T e max

Now, you see in the denominator of this expression of q who decides the value of T e max there is n s. This n s can be written as 2 f by p 2 f by p is not this n s and similarly this x 2 dash can be expanded as omega into l leakage inductance. So, it will give you another f here another f here therefore, you see T e max T e max is proportional to V 1 by f whole square it will be proportional like that. Therefore, since I am varying the frequency in the downward direction and also maintaining this V by f ratio constant V by f ratio constant I am maintaining therefore, it looks like T e max will remain practically constant remain constant.

If V 1 by f is constant; so, what happens to the torque slip characteristics? Now look at it very interesting what I do? All thing is this time since I am varying the frequency it is easier to rather sketch torque speed characteristics instead of torque slip characteristics why it will be clear. Suppose this is the thing this axis I call speed axis speed. And this is suppose the torque slip characteristics of the induction machine with V 1 rated and f rated this characteristics and this is the synchronous speed n s rated this is suppose the torque slip characteristics electromagnetic torque develop and rotor speed will be close to this 1 that is all.

Now, suppose you change the voltage to half and frequency also to half therefore, new n s 1 therefore, was n s 1 if you call it is rated n s 1 was equal to 2 f rated by p and this is n s 1. Now if I reduce the frequency by half and voltage also by half; the new synchronous speed n s 2 will be n s 1 by 2 n s 1 by 2. Therefore the let us see what will happen to that torque slip characteristics, when you have reduce both the supply voltage magnitude as well as frequency to half compared to its nominal values or rated values. Then it will be n s 2 which is equal to n s by 1 will the T e max will change? No, it looks like T e max will remain same.

Therefore I draw a dotted line here and it is expected that the torque slip characteristics will be also like this approximately. Only thing is this slip of course, I am not plotting slip this might change a bit, but anyway this torque slip characteristics will come like this. Therefore, when you reduce the frequency, you can draw then y at half for various values of frequencies you can draw the torque slip characteristics. So, machine will run at n s 1 at this speed at this speed a very smooth control of induction motor speed will be possible are you getting a number of characteristics I have drawn. V by constant f decreasing it can be nicely drawn, but anyway this is the idea ok.

Now, what happens say this is an equivalent equations I have banked upon is this equations, what happens if there is r 1 x 1 magnetizing current all this things are present? Oh in that case what will happen is this, this T e max will decrease as you vary decrease the frequencies.

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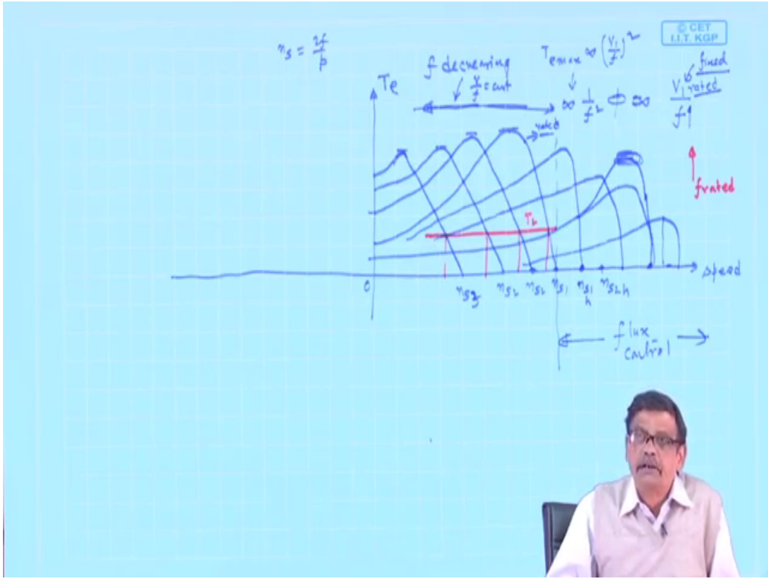

A bit for example, 1 characteristics will be like this. The next one synchronous speed is different its value will not really remain same it will become less because of extra drop in r 1 x 1 because Thevenin's voltage and supply voltage there will be a small difference the drop in r 1 x 1 and it will be another will be there.

So, at lower speed the peak value in fact, will never be equal to the peak value of the torque corresponding to nominal values of voltage and frequency. So, it will be something like this here so, n s 1 n s 2 and so on. In fact, you can run it down to very low speed low torque is suppose like this, then machine will run at this speed as this speed at this speed at this speed. So, same low torque can be supplied at lower and lower rpm.

So, you must understand that instead of drawing slip will be different in different frequencies n s minus n r by n s. So, that will be somewhat confusing it is better you draw absolute values of speed and torque. So, a smooth control of speed is possible in this way. Now the question is. So, this is in this curve I write it that f decreasing. Because of some practical limitations you cannot go maybe frequency less than 10 hertz that is because the drop in r 1 x 1 will be too large for that current.

But none the less you can go down to very low speed over a wide range that is you vary it, it will run will it incur extra loss? No not at all assume there will be some switch the losses in the inverter, but that is much smaller compared to rotor resistance starter, where you kept the rotor resistance when the machine was supplying load. [FL] Now the question is so, this T e max will decrease a bit because of because these equations are only true if you neglect all stator impendence anyway that can be done.

Now, the question is what happens can I run this induction motor higher than its rated speed? The answer is yes by varying frequency because frequency can go down from its nominal value rated value or you can make it also high for example, 50 hertz motor I will supply it from 55 hertz synchronous speed will increase or say 60 hertz because my inverter block will provide me that kind of frequency variation no problem. Therefore, if you increase the frequency, then how these torque slip characteristics will be changing [FL]?

Before I discuss suppose I want to also increase the frequency so, that I want to run it because you know in dc motor control, you can control the speed below the rated speed by controlling unmeasured voltage similarly you can control the speed of the dc motor at higher values by controlling the field current. Therefore, it may be necessary to control the speed both down and up about the rated speed of the motor. In that case what should be the strategy? Look at this equation now I am telling I will write it here.

Now, we know this was most important thing deciding factor that is phi is proportional to applied voltage by frequency. Now what I am telling, I will increase the frequency from its rated frequency f rated; 50 hertz I will make it 60 hertz like that. Now you see in this equation and V 1 is what? Corresponding to suppose V 1 is rated I know by this time that if you decrease the frequency your numerator V 1 must be reduced by same proportion otherwise saturation will take place.

But in the other case if you want to increase the frequency, the saturation problem will not be there because if you fix 1 must understand that if you apply 60 hertz should I apply a voltage which will be 6 by 5 into V 1 rated? No that is what I want to say because the winding has got a rated voltage based on that the insulation has been provided in the machine. Therefore, when we talk about increasing the supply frequency in order to run the induction motor at higher than its rated speed, then it is obvious I cannot touch V 1 rated it is already V 1 rated say 400 volt machine 440 volt machine.

Although I will increase frequency, but I will not touch V 1 rated, then it will machine will be stressed rated voltage above rated voltage I should not apply that is the rule. Therefore, V 1 rated in this case will be fixed then you talk about increasing the frequency because then flux will go on decreasing and so, on. Now the question is, how the torque slip characteristics then look like. Go by this equation once again qualitatively let us see now what I am doing? I am keeping this T e m x T e m x roughly proportional to we have seen V 1 by f whole square.

Now, what I am telling in this particular case, it is inversely proportional to f square because V 1 rated this fixed therefore, the peak value of the star will reduce drastically as you go on increasing frequencies. However, this synchronous speed will go on increasing because synchronous speed has nothing to do with voltage n s equal to 2 f by p you have increase the frequency synchronous speed will increase. So, if I draw vertical line here this is the f decreasing keeping V by f constant keeping V by f constant this zone.

In this zone I will increase the frequency keeping the rated voltage applied to the machine constant ok. Because you know if you increase frequency keep rated voltage physically also we can say flux per pole decreases therefore, torque must decrease. All though equations are there to support me, but anyway that way also you think you are decreasing the frequency therefore, it will. So, how the torque slip characteristics will look like?

Your synchronous speed will increase with respect to this rated voltage, it will be like this. Then you want to I am sorry I should draw it here ns 1 ns 2 ns 3 it was it is some ns 1 higher speed h ns 2 higher speed. So, this will be like this. What I want to tell this will decrease quite fast you forgive me for this higher speed. The peak value will go on decreasing because inversely proportional to frequency. Therefore, we see that if you want to control the speed of the induction motor the elegant way to do it is control the supply frequency do not start talking about I will change the number of volts, because nowadays very nice invertors are available and you can vary the frequency.

The movement the variation of frequency comes 2 questions must be answered. Suppose at rated voltage rated frequency machine is operating start from that point that decides the rated flux. If I decrease the frequency in order to run the machine below synchronous operating speed, nominal speed I must decrease the frequency, but while decreasing frequency. It will be suicidal if you keep the voltage at its rated value because of the fact saturation will take place it will demand much and higher and higher magnetizing current all the problems of saturation will come in.

Therefore, while decreasing frequency voltage applied must be also proportionately reduced such that T max will remain constant and that various synchronous speed the characteristics you can draw put the lot of characteristics point of intersections will give you the speed over a wide range down to a very low speed you can control the speed of the machine. Can I control the speed of the induction motor above the rated speed? Yes, you can by increasing the supply frequency should I once again then increase the applied voltage in the same proportion so, as to get same flux? No there is a restriction.

Supply voltage applied to the machine should not be exceeded from its rated value. Therefore, while running the speed at higher than its operating speed you must make sure V 1 applied this is rated condition torque slip, V 1 applied is held fixed increase the frequency then the torque slip characteristics will be like this. Therefore, it is just like this portion is called actually flux control compare to dc machine if you see ok.

You are essentially keeping v fixed f increasing if you do f increasing flux you are decreasing flux per pole. Like in the higher speed if you want to run a dc motor from its rated value you have to decrease the field current flux in the machine is reduced. So, all this things now come out very nicely that you can also control the speed of the induction motor over a wide range.

Thank you we will continue.