Control Engineering

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Lecture - 10

The two equations for the steady state operation of the drive are quite easy to solve the electrical equation is the applied voltage E a equal to the back emf term K b into omega m plus the armature drop I a into R a.

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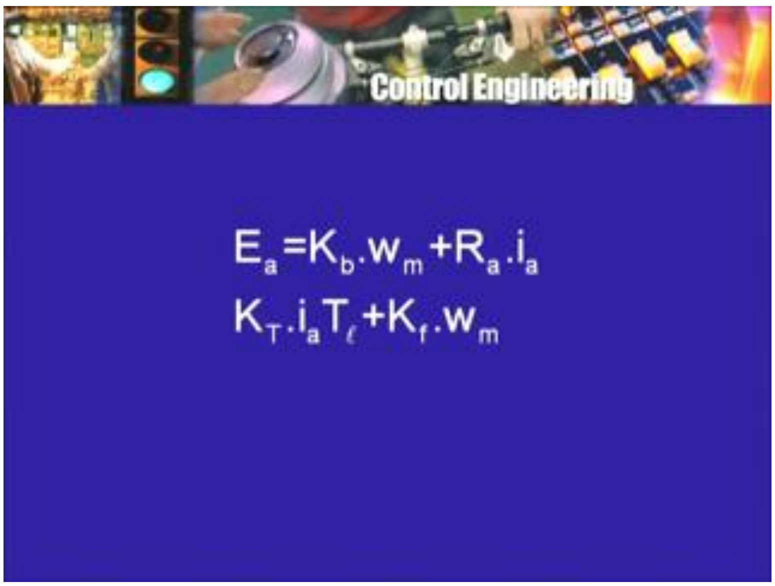

The second equation is the torque equation the torque produced by the motor winding K T into I a equals the load torque T l plus the torque required to overcome friction that is given by K f into omega m. It is easy of course to solve these 2 equations for the quantity of interest to us namely the speed of the motor or the drive omega m and here is the expression for omega m. It is a ratio of two expressions and the various parameters and settings of the drive enter into this equation such as the applied voltage E a, the load torque T l the back emf and the torque constants the armature resistance and the quotient of friction.

We are only looking at the steady state, so terms which were there in the equation under changing conditions namely the inductance term in the electrical equation and the inertia, moment of inertia term in the mechanical equations, so L a and J of the drive are missing here. So this gives you the speed under constant or steady state conditions. Now of course I indicated to you that we carried out the design in the reverse order that is we know what omega m we want we have chosen the motor, we are given also the rated lower torque and the applied voltage E a and so what we figure out is what should be the field current. So that the corresponding value of K b the back emf coefficient or K T the torque coefficient will make this equation true. The field current does not appear here explicitly but it is the field current which determines value of K b and K T.

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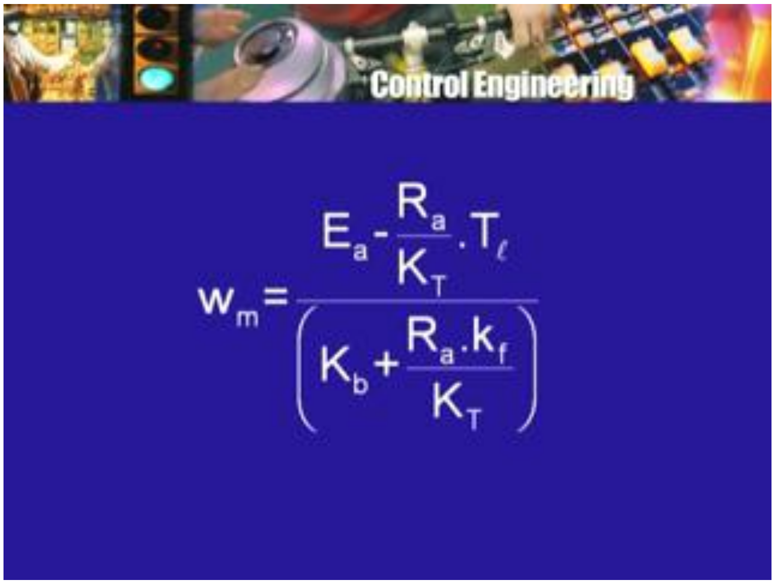

Now as I said from this equation we can see what is the effect of changes in values of these various numbers which enter into this equation. For example, if the load torque if the load torque goes beyond the rated value by more then by say 10 percent or we are looking at the no load of this condition, the motor is started on no load the load has not been connected. So that T l is equal to 0, we can calculate the values of the speed under various conditions and Bode had introduced what is called sensitivity coefficient or the idea of sensitivity to variations of this sort. For example, if one wants to look at the sensitivity to variations of the load torque then one can think of it as follows all the other things are kept unchanged the applied voltage etcetera only the load torque is changed.

So it is changed by small amount as usual by delta T l then the speed will change perhaps by also small amount delta omega m, one can think of the change in the speed in the relation to the rated value of the speed as the ratio delta omega m divided by omega and one could take it either as a fraction in which case it is referred to as per unit change or one may multiply it by 100 to get what one talks about as percent change.

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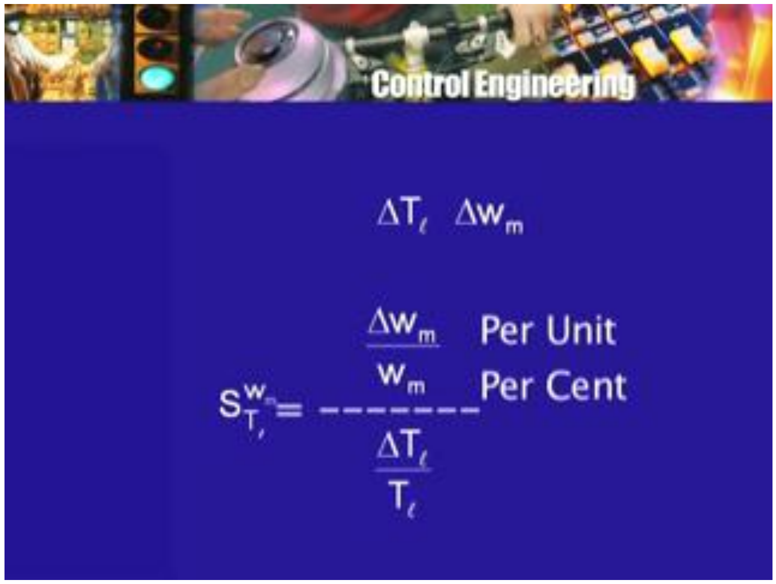

So the rated speed in our example is 1500 RPM and the speed goes down by 15 RPM then per unit change will be 15 divided by 1500 or .01 and the percent change will be one percent. So one can find out the per unit or percent change in the speed and then divide this by the per unit or percent change in the torque and this ratio of the 2 per unit or percent changes of the speed to the torque is referred to as a sensitivity coefficient, so one use the letter S for sensitivity and here to see what is it that is involved in the sensitivity. So let say as superscript I put omega m the motor speed and its sensitivity with respect to the torque variations, so this is what is being calculated.

Now in general if the changes are not small now of course what is small and what is large is dependent on the actual numbers in a particular case what may be small in one case, may not be so small in another case for example one percent change in torque may be small in one situation and may not be small in another situation. So if one thinks of changes which are going to be reduced and one looks at the limit as it were then in place of this change in speed divided by the rated speed and this fraction divided by change load torque divided by the load, rated load torque instead of this one can look at an expression that involves the derivatives.

So the derivative of the omega m, the angular speed and because it depends on many other variables or quantities other then T l, I am using the partial derivative notation here partial derivative of omega m related to T l the load torque d omega m dt l and T l divided by omega m. You can think of the partial derivative as being approximated by delta omega m divided by delta T l, in this case this expression will be the same as the previous one. So very often this is taken as the sensitivity coefficient. Now this gives you a relationship between the percentage changes only when the percentage changes are sufficiently small and as I said one does not really know beforehand how small is sufficiently small.

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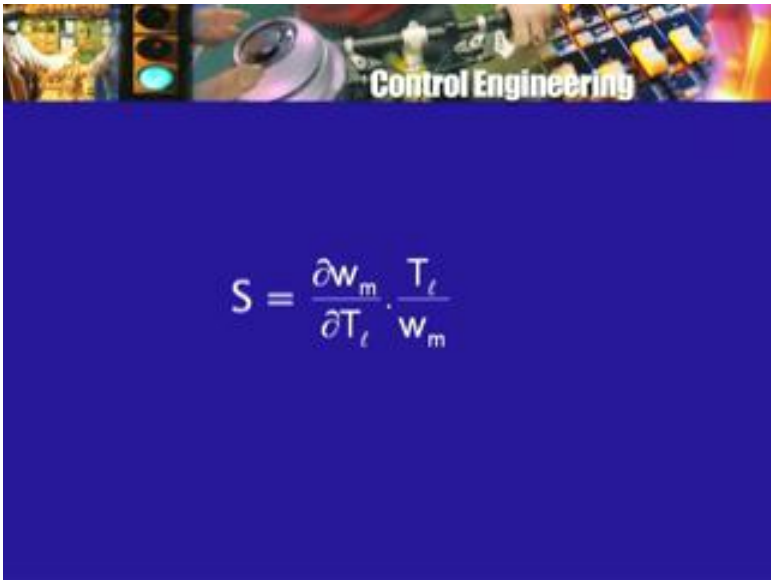

So in fact it does not at all difficult and today we are not worried about computation at all. So one can look at the expression for the angular speed and then evaluate the angular speed for the new value of torque rather than evaluate the sensitivity coefficient and then say that okay for so much percentage change in torque because of the sensitivity coefficient being let us say .1, the change in speed will be one-tenth of the change percent is change in the load torque. Now this exercise can be done for the other quantities for example the applied voltage.

So one could talk about variations in omega m when when the variations take place in the applied voltage other quantities remaining constant for example, the load torque remains constant etcetera. As we saw earlier these are the two variables which in a way can the thought of as disturbances certainly the applied voltage of course they are not from a practical point of view disturbances, the applied voltage E a is of course necessary to run the motor. So it is not a disturbance it is necessity, what is the disturbance is changes in E a or our lack of exact knowledge of E a. The design value 230 volts may not be what you actually have similarly, T l the whole purpose of the drive is to drive the load which is going to demand load torque.

So T l is not a disturbance in that sense but what can be considered as the disturbance is the possibility the T l is not known or T l is not at the value for which the calculations were made. So in this sense E a and T l could be looked upon as disturbances or rather changes in them or lack of exact knowledge about them could be thought of as disturbances and of course as far as the supply voltage E a is concerned one can find reasons for changes in E a. For example the same power supply is also supplying some other device which is getting switched on or switched off, as a result of which E a can change if the power system is not properly designed. There are the other numbers or quantities that appear in the equation and they are the parameters of the system such as the back emf coefficient which we saw will depend upon the field current and therefore, once again can be thought of a some kind of disturbance.

The field current is supposed to remain constant it is being supplied through some independent power supply but for some reason are the other that power supply voltage is not remaining constant and therefore the field current has changed. This causes will change in K b and K t, so all though it is a parameter it can be related to variable like I F which can then the thought of as a disturbance but for the moment if we ignore how K b changes then a change in K b or K t is a change in parameter value.

Similarly, for the frictional coefficient K F and the armature resistance R A. Well, it can be a change in parameter value that is under actual operating conditions something happens and therefore R A under an actual operating conditions is not what it was, when it was measured perhaps but there is also the other fact that no parameter value is known exactly any physical measurement has always associated with it besides inaccuracy also precision. The best of instruments will have limited precision it could measure within one millimeter or it could measure within one micrometer but that could be about all.

So either change in the parameter value or lack of exact knowledge about the parameter the value both of these effects can be thought of as causing omega m to be different from the designed value and you can go through this exercise as I told you as homework what will happen if R A changes or it is known inaccurately and actual armature resistance is 50 percent more. We thought that it was one ohm when we designed the drive but it is 1.5 ohms, what difference will it make to the speed similarly the coefficient of friction and the back emf of and power constant. Now as I said such calculations one can make if as a result of such calculations you find that the speed changes such at power practical purpose it is okay, it is admissible, it is tolerable then the problem is over we do not have to go any further the drive as designed will work. Well, of course one has to remember that the preceding analysis I talked about changing E a and changing T l etcetera was very simplistic.

Assume that E a remains constant and T l only varies or T l remains constant and the applied voltage varies, these are just assumption. In practice it could happen that E a changes and T l also changes and it could happen that the 2 changes conspire against you and therefore make the situation worse than it could be if there is only one change I suppose you have enough feeling for the drive because of the 2 equations and the situation physical situation. To see that if the load torque increases and applied voltage decreases then the speed of the motor will decrease by a larger amount where as if the load torque increases and the applied voltage also for some mysterious reason increases the speed change may not be as much as could have been if only one of the 2 have changed and of course one could think of a very worst scenario or at least a very bad scenario when not only E a and T l change but the parameter values also are changed or not known within desirable accuracy and so with all these things the speed change may go out of the admissible or permissible range. The drive may not have a good regulation, what is good is ultimately decided by the user and so one has to find out from the user whether the percentage change that may result is tolerable or not.

Now as when we went through the design, we saw that the load torque the speed and the motor characteristic or the motor parameters fixed the value of E a or therefore we had to think of for a given E a changing the value of K b and K t by changing the field current. Now what if you want the same drive to operate at another speed and may be another load condition instead of 1500

RPM you want to drive a load which runs at a much lower speed. Let say it runs at speed of only 500 RPM where as the load torque is still equally large then the same expression can be used and you will see that you apply the same armature voltage then the speed of course is going to be close to 1500 RPM.

So in order to make the motor run at a lower speed we will have to change E a not by small amount by but by considerable amount. If you look at the electrical equation the back emf is nearly equal to the applied voltage if the armature drop is small which it is and so roughly for a given motor the applied voltage will be proportional to the speed. So if for 1500 RPM you have two thirty volts DC to get 500 RPM one-third of the speed, the applied voltage will have to be closer to one-third of 230 volts. So in other words there has to be a large change in the applied voltage.

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Now what if such an applied voltage is not available because you are getting commercial supply which comes at only 230 volts value. So this problem arose a long time ago and there is a simple minded solution namely if you need a smaller voltage then in series with armature connect a resistance. So that the voltage across this resistance will reduce the applied voltage but you can see that the thing is not desirable again we will make some qualitative analysis, exact expressions will come later. Say, 230 volts applied voltage is split up into about say 220 volts of back emf and 10 volts of armature resistance drop. The armature current is determined very nearly by the load torque because the load torque is larger part of the total torque, the frictional torque one expects will be a small part of the total torque.

So qualitatively, we can say that if the load torque is going to be the same then the armature current will be same, if the armature current is same the armature drop will be nearly the same, 10 volts. Now I want the motor to run at one-third of speed therefore the and I assuming that I am not changing the field current of course that is one method of control and we will and it is used in fact for the moment let us say that I am not able to manipulate the field current. So the back emf and torque constants cannot be changed then the back emf has to be dropped to one-third of its value say roughly something like 73 volts.

Now there is an applied voltage of 230 volts, there is an armature drop of still 10 volts because the armature current is going to be nearly the same. The back emf is now considerably less why because the applied speed, the speed that you want is less so as result you have 230 volts applied and there only 83 volts accounted for which means that the balance of it has to be dropped in additional see in a series resistance explicitly connected in series with the armature not like the armature resistance which it is the part of the whole thing, you cannot have an armature winding without resistance. Here now I have to in insert in series with the armature a resistance of some suitable value what the value is does not matter but roughly we know what the voltage across it will have to be.

So it will have to about 157 volts because 230 volts as we can check quickly is 157 volts plus 73 volts plus 10 volts or is it 147 volts may be 147 volts. As I said at this point we are only making qualitative assessments so exact numbers are not so important although one should have some judgment about their relative value. So 147 plus 73 plus 10 does it add up to 230 yes, it does the point is this 147 volts is going to appear across the resistor of the total voltage 230 volts.

Now look at the electrical power 230 volts is supplying a current of let us say 10 amperes, 10 volts armature drop is say 10 amperes across 1 ohm armature resistance. So the electrical power that the motor is drawing from the supply will be 230 volts into 10 amperes out of which 147 volts into 10 amperes is appearing in the resistance that you have connected in series and this resistance getting heated and so this energy is being wasted in other words you are drive is running at the correct speed perhaps but it is inefficient, it is considerably inefficient. The motor is driving the same power although the power that is being supplied to load is one-third and one can see why it is one-third, the torque is the same we have assumed that the torque is the same but the speed is one-third. So the mechanical power required by the load is one-third, so the efficiency of the drive if originally it was close to 100 percent, it cannot be 100 percent, it will be now of the order of one-third of if it will be of the order of 30 percent or so obviously this solution is not the correct one. Now so we cannot use the series resistance to take care of this or to allow us to change the speed of the drive to any value that we may like.

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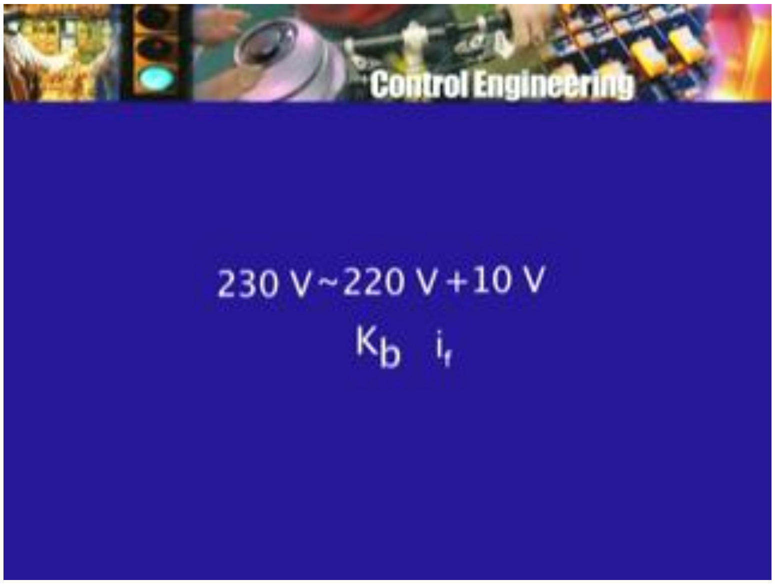

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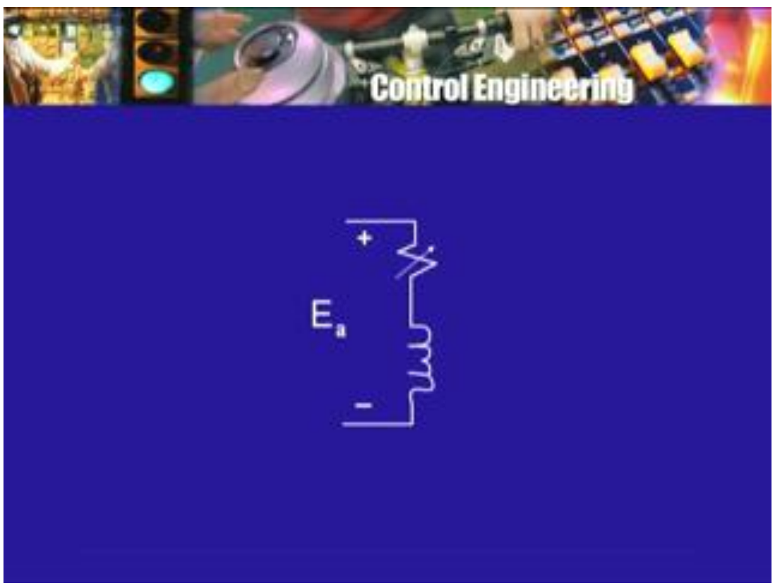

Of course as we saw earlier we could change the value of K b and K t. So that the back emf term remains the same although the speed has gone down. So 230 volts continues to be 220 volts of back emf and 10 volts of armature drop, armature current is still 10 amperes across through one ohm resistance. The back emf is 220 volts but this source being produced at 1500 RPM earlier and now it is to be produced at 500 RPM one-third the speed. So which means that the back emf coefficient K b should be 3 times which roughly means that the field current therefore should be three times. Now that may not be possible the field current is produced as a result of connecting the field winding across some specific supply voltage, it so happens that the unlike the armature winding resistance the armature resistance has to be small as we saw the armature conductors are thicker.

They also carry a larger current and because of this the armature winding has a smaller resistance the field winding is a different one, the field winding first of all may require a much larger number of turns therefore will have a longer length and to economize and the current that it is going to carry is also going to small compared with the armature current the armature current is 10 amperes, the field current may be an ampere or 2 amperes. So the field winding resistance is not going to be small. As a result if you want have 3 times the field current, in the field winding the voltage that is applied to the field winding that may not be adequate.

So now I have to have a field winding for which the supply voltage can be increased. There are of course limits to increasing the field current as I mentioned earlier because of saturation. Even if you increase the field current the magnetic flux or flux density may not increase proportionately after a certain limit, in fact it will be more or less accurate. So there is a limitation on this approach also but certainly variation of field current can provide or can allow you to change the drive speed, of course the change in field current which changes the K b and K t will have an effect on the armature current if I increase the field current 3 times, so that K b is 3 times then K t is also 3 time. So to produce this same torque I require one-third of the armature current therefore the armature drop will be little less and so on.

So there are limitations of this way of changing the speed of drive, there are 2 adjustments therefore that one could make, one is the voltage applied to the armature winding and the other is the voltage applied to field winding. So let us say E a is the armature winding applied voltage and E f is the field winding applied voltage. If we assume that E f constant and therefore the armature current the field current is going to be constant then there is no way of changing the speed of the drive other than changing the applied voltage.

Now this problem was faced all most a 100 years ago, when the AC motors had just been introduced and had not become that popular and also that economical as they are today and AC power supply also was not that common initial applications of electricity required DC power supply for example, for electrolysis and others applications although as far as say heating is concerned it does not matter whether it is AC or DC. So variable speed drive requirement arose and one of the earlier applications was of course in locomotives.
Of course as I mentioned earlier, in a locomotive application such as in the Mumbai sub-urban system the configuration preferred is not shunt or separately excited motor but series connected DC motor. But in some applications you may prefer the separately excited DC motor and therefore a person with a hyphenated name just one single person by name Ward-Leonard and American engineer introduced this idea which looked and even today will look little not only a little complicated but involving too much of equipment, but it solved the problem and the idea was is as following you need a variable speed separately excited DC motor drive.

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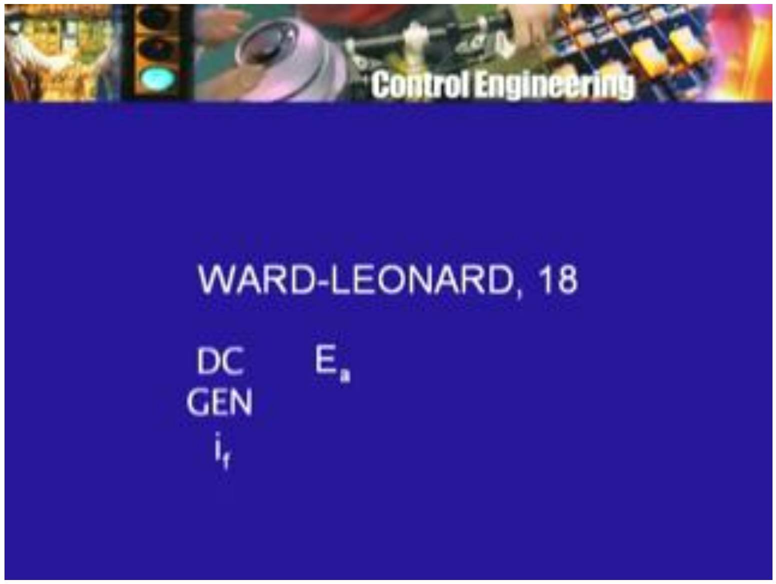

So for that you need a variable armature voltage supply E a in any case the armature voltage supply that you want may be of such value that you do not have it directly available to you. So you may have to generate it on your own those were the times 100 years ago when rectifiers were not as common place as they are today, the vacuum tube had just been the vacuum diode had perhaps just been invented. So you could not say okay have AC voltage rectify it and produce DC voltage so techniques which are available today for generating a DC voltage were not available at that time. So the solution was to have a DC generator which produced the required voltage for the armature of the motor which was to be driven but then the DC generator would require something to drive it.

Now that something to drive it could be an IC engine but it could also be an electric motor but so this why the whole thing may look like involving to much equipment. You have an electric motor which is connected to some load whose speed perhaps you are required to change over a large range and over a large range of torque values therefore you need a variable DC supply E a to produce that you have the DC generator which then has to be driven by a DC motor or an AC motor depending on what may be available but this gives you some flexibility because the voltage armature voltage E a which is then produced by the DC generator, the DC generator voltage could be changed and it can be changed one again by changing the field current of its speed winding.

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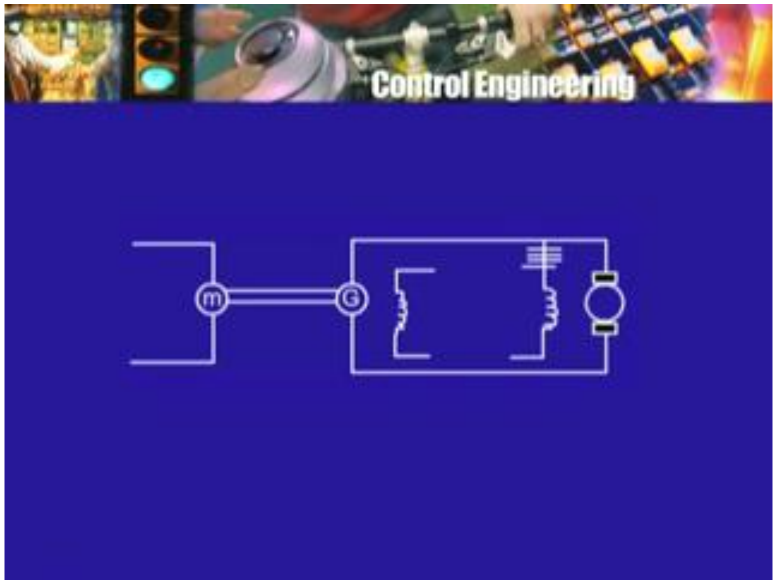

Now there is some advantage to all this if the power levels are sufficient etcetera etcetera and this kind of a drive was actually introduced it is merits and demerits discussed and it was actually being used in many industries Ward-Leonard drive or variables speed DC motor drive. So this just indicates that solutions are possible of various kinds. Although, today one would probably not use this solution for the simple reason that we have rectifiers available whose efficiency is very high and therefore desired DC voltage can be produced from a fixed AC voltage supply that is a variable DC voltage can be produced from a fixed armature value AC supply and therefore you can drive a DC motor separately excite a DC motor at various desired speed.

Now to get back to the problem of sensitivity or percentage regulation of speed not being adequate. The Ward-Leonard system the idea was not to improve the regulation basically but to provide the possibility of large variation in the steady value of the motor speed, in one application the motor speed was required to be 1500 RPM in another application perhaps it was required to be 500 RPM, how to handle this situation that was the reason for the Ward-Leonard system with a motor generator or engine set producing a DC voltage which is then connected to the motor which drives the mechanical load. So its main purpose was to allow for variable speed operation. We will now look at the techniques or ideas which were introduced to improve the regulation of the drive or to reduce the sensitivity of the drive.

So we will assume that the motor is to run at 1500 RPM the application is such that it requires 1500 RPM, the crude design or the simple minded design is that is do nothing but just apply an armature voltage keep the field current constant at some pre determined value and that say do nothing more the percentage change or the change in speed that may result, may not be acceptable. So we have to do something about it now right from the beginning of the course I have said that in any application there is always human being somewhere or the other who can be brought into the picture. So in this case of course one can say that let an operator monitor the speed of the motor.

So the first thing that we have to do now is to find out actually what is the speed of the motor under operating conditions while the motor is actually operating and driving the load. The pre calculations the pre programming has told as that the speed will be 1500 RPM provided the applied voltage is exactly 230 volts, the load torque was exactly so many Newton meters, the armature resistance was exactly one ohm and so on and so forth. So that those were the pre calculations but when the motor is actually operated the speed will be different from the theoretical absolutely constant speed. So one will have to measure the speed, so this is the first requirement in order to do something I have to measure the speed and as I said earlier it is not very difficult to measure the speed electrically.

We can mount a small generator on the same shaft as the motor and the load, a small generator could be a permanent magnet type of generator or what is called magneto and so it can produce a small DC voltage which is reasonably proportional to the speed. This generator is call a tacho generator and therefore we can put this tacho generator and get a means of assessing the actual speed of the motor.

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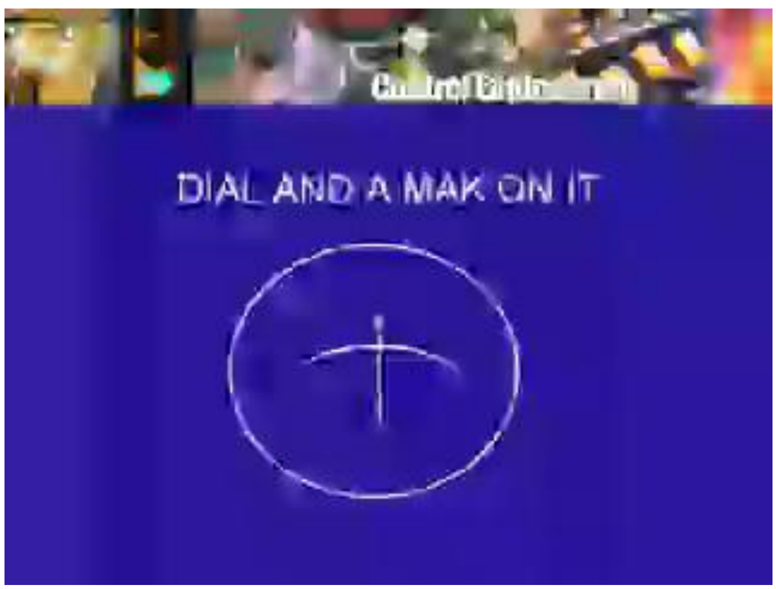

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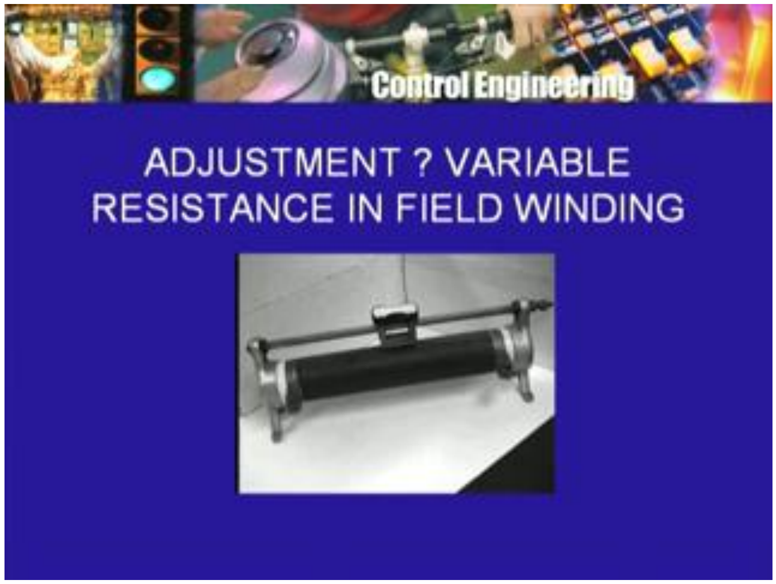

Let us say 1500 RPM if the motor actually ran at 1500 RPM therefore the tacho generator also at this speed then the tacho generator perhaps would produce a DC output of 20 volts. Now we can bring in the human operator, the human operator can monitor the drive by looking at the tacho generator voltage, there can be dial on which on does not have to write any numbers but one can put a red mark or black mark or whatever if the motor speed is 1500 RPM the tacho generator voltage is usually such that this meter pointer will be at that mark.

Now the operator has to keep on looking at this instrument dial of course he has to be given some means of making adjustment. So that the pointer remains against that mark all the time and the only adjustment that we can think of given our situation, applied voltage is not going to be changed. There are 2 adjustments that are possible of course we already talked about and that is varying the field current. So one can provide a small variable resistance in series with the field winding and the operator can then manipulate the slider of this resistance. So that the speed is at the arrow or at the mark, this is one adjustment that the operator can make, the other adjustment which is not so desirable is to have a small variable resistance is series with the armature and the operator can vary that resistance to maintain the speed constant.

Now once again one has to make some calculations how much resistance, no total resistance in the speed circuit should one think of how much resistance in the armature circuit which is better of the two and so on and the sensitivity calculations that one can do and I have asked you to do are helpful in this regard, is it better to vary field current by changing this resistance in series with field winding or is it better to vary the resistance in series with the armature circuit better meaning what of course better meaning one is power, the other is slide change here and slide change there. If it is too sensitive to field circuit resistance then you can imagine what is going to happen something happens the speed drops down.

So the operator who is going to change the field current by varying the resistance what will he do the speed has dropped due to some reason I want the speed to go up speed is related to back emf.

So I must make the back emf increased to the make the back emf increase then I had to increase the field current, no I have to decrease the field current speed has dropped, I want the same back emf, I want the speed to go up, so what changes should I make think about it. Of course the operator will not have to do this thinking he can be trained or if by using experience he can figure out that if the speed goes down then the slider of this resistance or rheostat should be moved to the left or should be moved up or down and so in fact one can have arrows there or some indication there like increase and decrease. So the operators simply looks at the background where this is written against the slider and one way moment of the slider says increase the speed the other says decrease the speed, so that what it does. Of course something like this could be done for the resistance in series with the armature.

Now this is of course manual control, the operator is going to be observing the speed all the time so for that we need an instrument such as the tacho generator and he has to be provided with some arrangement like variable resistance in the field circuit or variable resistance in the armature circuit. So that he can manipulate one of these to maintain the speed as the nearly constant as possible. Now there are some obvious drawbacks or limitations of this way of solving the problem from some point of view one may say well you are employing an operator whose is going to be sitting there all the time.

So we have to pay him that will add to the cost but that is not the only aspect, the operator is going to be seated there all the time. So long as the drive is operating the drive may be in operation not for few minutes but for hours if the operators has to be seated there in front of the dial and with his hand on that slider and as things change he has to go on moving the slider up and down or left and right or what have you. So this will result in fatigue this is a very monotonous job and it will result in fatigue after sometime the operator may doze off or may take wrong decision the speed goes down you should have moved the slider in this direction but he is not alert enough he moves it in the wrong direction the speed goes down further.

So he moves it further in the wrong direction till he realizes something has happened. So now one can make a over correction, the correction may not be adequate or the correction may be in excess. So it is not really a correction but results in error, the field current is decreased a little too much or increased a little too much. So that the speed which was originally was probably below fifteen hundred now goes beyond 1500, so it has to brought down once again. People did look at the human operator as if he or she was mechanical system or an electric system in other words one could do a modeling of the human operator, people talk in this context of reaction time and this is one more reason why you may not want the operator there apart from fatigue, the operator takes some time to notice a change and apart from the precision involved here the pointer is very close to the mark, very small change in the moment of the pointer may not be noticed by the operator.

So unless the error is large the operator will not act more over when he acts there is slight delay he is looking at the dial speed has dropped then is hand on the slider has to move and there is a physiological system involved with in the eye seeing something and then the hand of person moving and this has been studied models of the human operator have been made. They are made not for such simple reason of purposes but this was really done for aircraft pilots and of course air force pilots where this is much more important and ultimately therefore the ideal or the objective was to have pilotless aircraft which can be sent over enemy territory or which can intercept enemy aircraft.

So fatigue reaction time the fact that an operator may not notice a very small error, these are among the various reasons for which you may not think of this solution at all as a good solution. It is a beginning but it is not a good solution you do not want this to be done manually therefore you wanted it to be automatically and of course control is not just manual in fact it is more and more automatic. All though as I told you right in the beginning some element of human supervision will still remain in any significant application ultimately somebody will be looking at what is going on and will switch of something or shutdown something and so on which may not take place automatically. But we want therefore the manual control to be replaced by an automatic control and how can we do this.

Well, we have to arrange for some automatic system or device where by what the human operator was doing will now be done by this automatic system. This automatic system now is something which we did not have earlier and this therefore is sometimes given a name and is called controller, it is not as if there is no controller in the earlier situation but all those were steady state calculations and no further changes therefore not much of control was visible there but now we are going to see whether the speed change could be reduced by automatic means. So we need some additional piece of equipment which is called the controller.

Now what will the controller do, what the controller will do can only be what the human being could have done. In other words whatever the human being could do or we thought of providing for the same thing we can provide for automatically and this where the earlier classification of speed control of a motor into field control and armature control will come in. The operator can adjust the speed by changing the field current. By instead of the operator adjusting the speed you could have an automatic device or controller in which these adjustments take place if that is the case then we are looking at speed control DC motor and as I said this is one way of controlling the motor not by manually changing the field current but by automatically changing it or adjusting it. This is a speed control motor but we are looking at the other type or technique namely armature controlled DC motor that is the applied voltage will be changed.

Now for change in applied voltage then we can do what the operator was doing namely a series resistance, a resistance in series with the armature was being adjusted by the operator. So we could have that operation done automatically or we can go back to the Ward-Leonard system where the applied voltage E a was being produced by inverter generator set and the applied voltage was adjusted by adjusting the field current of the generator. So in a way it is making an adjustment of the field current but not adjustment of field current of the motor but adjusting the field current of the generator.

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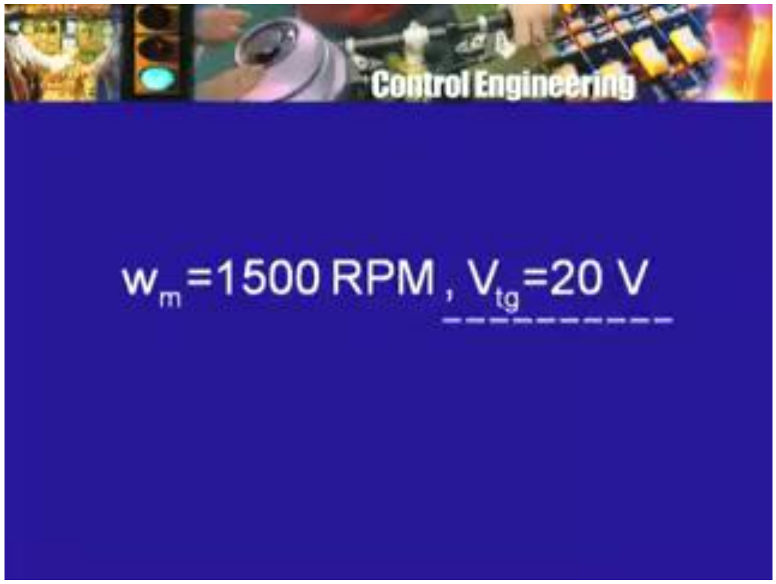

So you can imagine a Ward-Leonard system in which the operator still plays a role, the operator adjusts the field current of the generator or rather than adjusting the speed current of the motor. Now if the operator is to be removed we have to put a mechanism or controller which will change the speed current of the generator field winding. Now how is this adjustment to be done what mechanism and there are of course several alternatives. Now this is where some misconception can arise, so we have the look at it a little carefully. There is the desired speed omega m 1500 RPM in our running example which is measured by the tacho generator voltage output which remains at 20 volts.

So if the tacho generator voltage is 20 volts unless the tacho generator is malfunctioning or its speed have become weaker or whatever we can rest assured that the speed will be 1500 RPM. So if the tacho generator voltage or if the speed 1500 has not changed then there is nothing that we have to change which means that we are have to make changes either the human being or operator or automatic device, the controller will have to make changes only when the speed changes, the speed is no longer at the desired value or the tacho generator output voltage is no longer at the excepted values of 20 volts. So this means that you can take corrective action only after an error has resulted and been noticed.

So only when the operator notices that the speed is less that he moves the slider and we are not of course looked at the transient behavior of the drive. We only look at the steady state behavior of the drive when changes take place load torque increases, applied voltage decreases and so on. The speed does not change instantaneously if it is new value but it takes sometime for the speed to change and the 2 derivative terms of 2 inertia elements in the drive are responsible for this namely the armature winding, inductance L a and the moment of the inertia of the mechanical part of the system namely J.

It is because of these that current cannot change instantaneously in the armature winding or the speed cannot change instantaneously. The motor speed will change that means there will be an acceleration now that requires because of the moment inertia an additional torque or it results in an breaking torque. So there will be time delay and therefore there will be this error which will be there for some time. In the case of the human operator of course there is the problem that the operator may not notice the error immediately, he has is own reaction time may be one is not looking at the dial all the time therefore by the time you look back at dial the speed had already changed and then you react to it by noticing the change and then moving the slider, this increases the time delay still further.

So to get back to the idea or change will take place only if there is error. So sometimes the resulting system is said to be operated by the error or it is to be driven by the error error operated or error driven system. Now this gives rise to wrong impression certainly what motivates the operator to move the slider is the change that is he has noticed but if he is good enough or experienced enough this is where the skill of operator comes in that he will be able to reduce the error to 0, he will be able to adjust the slider of the rheostat. So that the speed is back at the rated value so an adjustment was made the field resistance, the winding resistance was changed starting at sometime and at stopping at sometime but there after no change was required and there was no error.

So the correction or the adjustment occurred because of the error but it will not be correct to say that therefore the drive is driven by error what the error drives is the correction and not the value of the speed. Later on we look at what are called error constants of various kinds of the control system and this is where this misconception can easily arise. But one should note right now that even the speed back now just looking at what omega m actually is and then making changes or adjustments is feedback whether it is manual or automatic. We have to tolerate some error for sometime for the transient period, when the load has increased suddenly unless you have zero moment of inertia zero inductance, an operator who has no reaction time or an automatic controller which has no inertia, no inductances and things like that it responds instantaneously unless you have a such thing there will be error during the transient period.

It is only an ideal case that a new load therefore a new value of E a or a new value of field current can change the value of field current instantaneously or change the value of the applied voltage instantaneously. So that the error is only momentary it is hardly seen that it is corrected in practice it is not going to the like that one may have to have or live with error for a short period of time. Obviously, the period of time should be very short we would like the error to be reduced to 0 as quickly as possible and so you would like the adjustment which is to made because of this error that adjustment should be complete as quickly as possible in such a way that the speed is restored to its final value.

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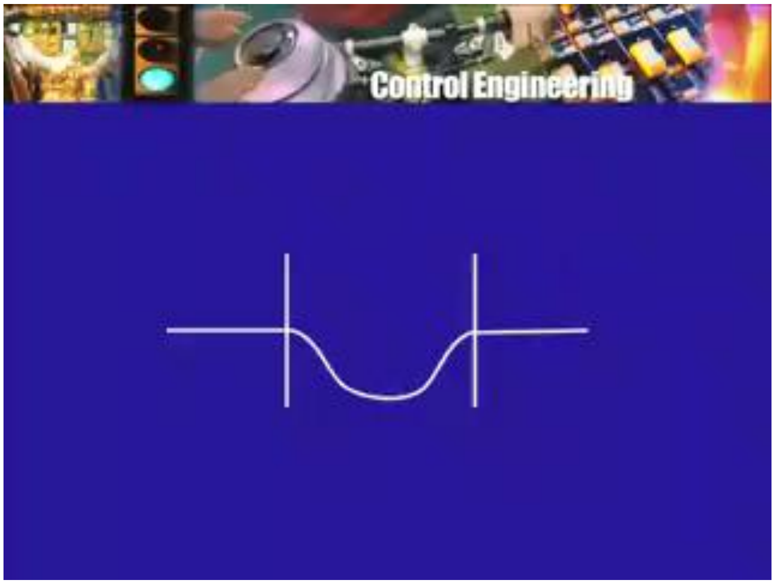

In our case if load torque has increased if the field current is maintained constant that is if we are thinking of only armature controlled DC motor then the armature supply voltage E a must go up which means therefore that the field current of the generator which provides power to the motor that field current must be increased and increased in such way that eventually after a delay of a few seconds perhaps the field current is at some new value, the armature voltage has increased to some new value and with this increase load torque, the motor continues to operate now at the same steady state speed as before. So in between during the transient period that the speed may have dropped. So if one looks at the variation of speed it would be omega m is constant till the disturbance the change in the load torque took place the speed referred dropped and may be it remained at a lower value till sometime when the adjustment was completed and the speed is back at its old value omega m.

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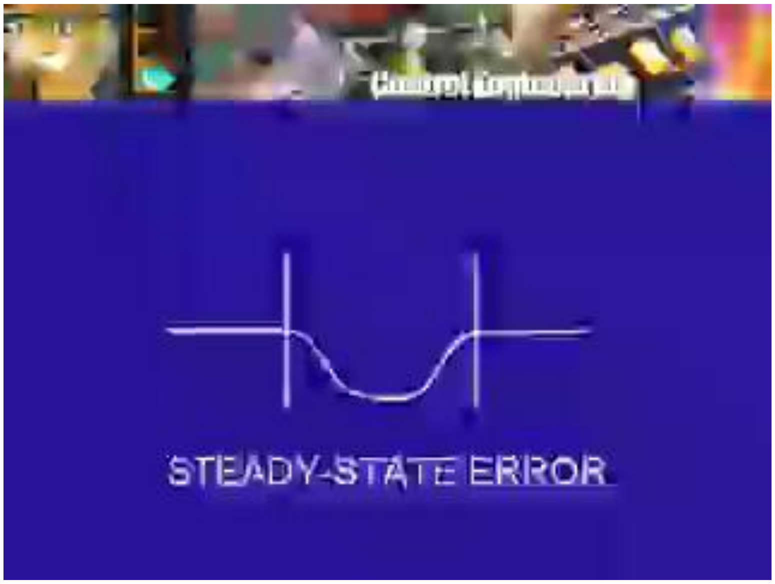

Now if the speed did not go back to its old steady value but went to some other steady value then one could talk about steady state error. This is different from the transient error which is unavoidable you can reduce the duration of the transient error can make it quicker may be not a minute a few seconds or even less than a second and so on. But you cannot avoid it altogether but after this transient period my new adjustment must be such that the speed is back its old value and therefore there is no steady state error. Now to repeat it is in correction with this error, steady state error, error driven or error operated systems such words and expressions that one may get a wrong idea of what is going on.

Our very primitive drive where E a was kept constant, field current was kept constant suffered from this defect that there would be steady state error, if the load torque changed the speed will change, may be by 1 percent but it will change and remain at the changed value. If accidentally the supply voltage changed the speed will change and remain at the new value. So that drive had steady state error and therefore of course we thought that it was not good or it may not be good in some situations where the steady state error that will result is not acceptable but now that we are introducing this element of feedback of manipulating or making adjustments. So that the error may be transient, our controller must such that there is no longer any steady state error.

Now in this context, we will look at the Ward-Leonard type of control system and look at what kind of feedback arrangements one may use and see that it is possible to make the arrangement in such way that there will be no steady state error after the load condition may have changed or some parameters in the field current may have changed or things beyond our control. We will see also that if one does not look at it very carefully one may conclude that that drive provides or results in steady state error although it does not. So I am talking about an automatic controller which will control the field current of the generator which will result in adjustment of the field current of the generator in such way that when the load torque has changed, the speed will go back to its steady value.

Of course that kind of controller is going to be little complicated it would also mean that we will have to look at the equations of the drive not only in the steady state but equations that are applicable all the time in other words if equations which involve derivatives and so we will have to look at differentially equations and their solution and so for. We will also draw some block diagrams which are fairly standard ones, which also useful and necessary to get some insight into what is going on. But again I will point out that some of the things associated with diagrams can lead one to wrong conclusion but what one can anticipate is the following the only measure or speed that we have at this moment is the tacho generator output voltage which is to be at 20 volts if it is not 20 volts the speed is not at the rated value and therefore there is error and whatever adjustment is to be done must be such that the tacho generator voltage goes back to 20 volts.

So in these sense 20 volts is talked about as a reference voltage is the speed is not 1500 but it is say changed to some other value then the tacho generator voltage will be of some other value and we will talk about a different or new reference voltage. So this is term that very often used in this case it is voltage in general one talks about this as the reference input.