Analog Electronic Circuits
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Lecture - 06
Analysis of Simple Non - Linear Circuit (Contd.)

So welcome back, I hope you have solve the numerical problem and as I said that you yourself have try to see, whether it is converging or not. But, interesting thing is that this kind of method is very impractical for an analysis, because even for simple circuit if we have to go through number of iteration and as I said that based on the slope.

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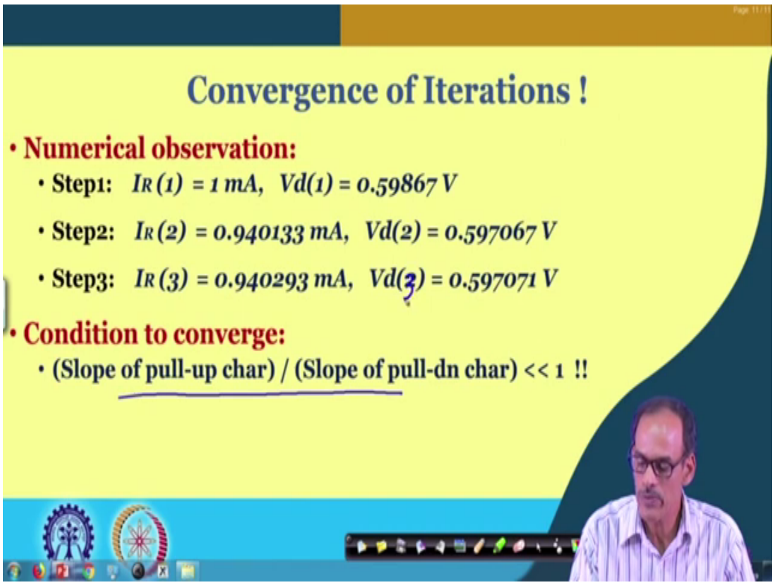

The convergence may or may be there or it may converge, but it may take more time based on this condition. So, it may not be good idea to stick to this one it is better to look out some other alternative ok. There is a small correction here this supposed to be V d 3 anyway. So, let us move to what may be the practical method or can we have method to solve just by one step itself.

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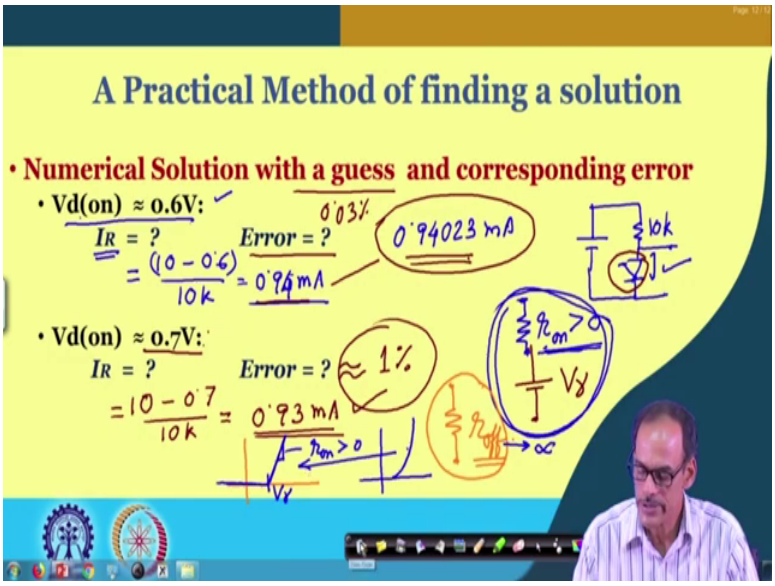

Yes, if we consider the same numerical problem, namely if I consider the V in here and then we do have the resistance of 10 k, and then we do have the diode here, and then if we observe the corresponding output, by considering one initial guess. And, this initial guess it is not just arbitrary, typically we know that if it is silicon diode and if the diode is on the drop across this diode is roughly 0.6 volt.

And, with this guess, if I consider V d equals to 0.6. The value of this I R you will be obtaining it is 10 volt minus 0.6 divided by 10 k. So, what you are getting here it is 0.95 sorry 94 milli ampere. Now, if you compare our the previous numerical value, which it was close to if I recall correctly 0.94023 something like this milli ampere. So, if I compare this value, this value after third iteration you obtain versus this one, what we have it is the amount of error it is in fact, less than I should say 0.03 percent. So, we can say 0.03 percent.

So, then just by one step itself we can find the solution. This is of course, one indication that how we are trying to get a practical method by the virtue of guess and proceed by one iteration, but then some people may say that no I do have a diode, it may be silicon diode, but I know that it is diode drop it is roughly 0.7. And, if we use a instead of 0.6 if you use 0.7, then also if you see the corresponding value of this I R is 10 minus 0.7 divided by 10 k.

So, this is it is coming 0.93 milli ampere. Of course, it is slightly different from this value; it is not as close as this one, but still if you compare this value and this value. I should say this amount of error it is in the order of just 1 percent slightly above 1 percent. So, even with this much of I should say guess, we are getting some solution which is falling within this accuracy level of accuracy and most of the time for hand calculation, this may be sufficient, most of the time for engineering problem if it is well within 10 percent we may say this is sufficient.

So, this gives us one indication that probably we may have some practical method to replace this diode by a something call some model. So, what is that model? We may consider if the diode is on drop across this diode it is may be around 0.6 or 0.7 and let you call this voltage is V gamma. And, but then if depending on the current level, the voltage drop across this resistance diode it may not be remaining same.

So, whatever the little dependency of the voltage and current is there, that may be represented by probably another element call r on. So, depending on the context we may say that either this is 0 or it may be non-zero, and typically the value of this r on it will be small. So, what we are getting is that by replacing this diode by this simple circuit of course, here we have considered this is equal to 0, that is why with this whatever cutting voltage of 0.6 we are directly getting this value. And, if you are plugging in this meaningful value of this r naught you will be getting even more accurate result.

So, depending on the situation most of the time we may be using this kind of model for the diode, if the diode it is in on condition, on the other hand if the diode it is in off condition we may use different model. So, we may say that the resistance of the diode in off condition it may be quiet high. So, in that case the diode may be replaced by a simple register where this off resistance it may be quiet high. So, it may be even higher than 10 mega ohms or may be beyond that.

So, we do have 2 models; one is this one, another is this one and both of them are we can say you know linear. So, we may say depending on the condition of the diode we are going to replace by linear model, but then single linear model is not working we do have piece wise linear model. So, we do have one model here, we do have another model here. This slope it is representing finite value of this r on and this is the cutting voltage and this flat line indicates that r off it is very high ok.

So, we can say that this is the model will be using instead of using our exponential relationship for practical purposes. So, instead of this exponential relationship we will be going for this piece wise linear model.

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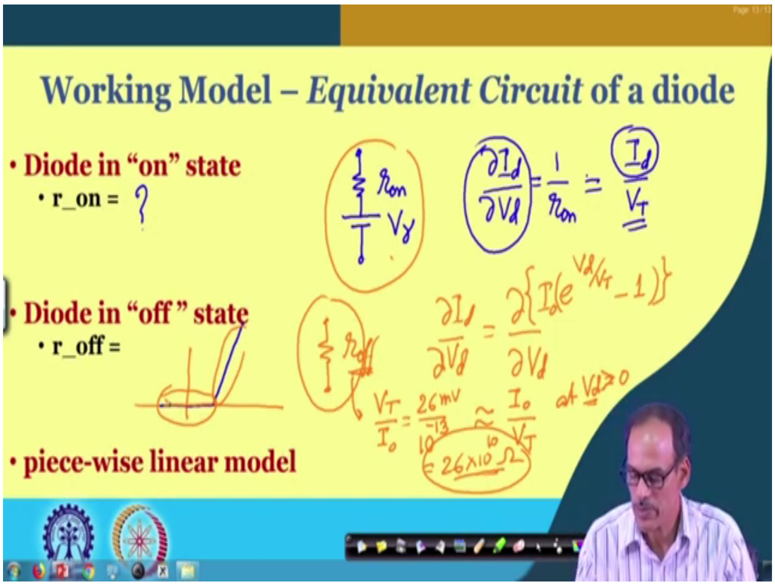

And, let us see how this model it is it can be used. So, let us move to the piece wise linear model more detail. So, as I said that if the diode is on we may replace this diode by simply on resistance, in series with V gamma call cutting voltage, and this r on. So, what is this r on? How do we get that? The change in diode current with respect to diode voltage is essentially this is 1 by r naught r on.

And, if you see this derivative of the I d with respect to V d that gives us I d divided by V T. So, depending on the value of this current and depending on the value of this V T you can easily find this voltage and as I said that V gamma you may be having a good guess around 0.6 or 0.7 that may be sufficient.

On the other hand if the diode it is in off condition as I said that this will be replaced by the simply off resistance. And, the value of this resistance again if this can be obtained by considering change in I d with respect to V d in cut off region. So, now what we can say that if I replace this I d by the I naught e to the power V d by V T minus 1. And, so if I take derivative of this expression of the current with respect to V d what will be getting is will be practically getting I naught divided by V T.

Particularly, this will be getting at say V d equals to 0. In fact, this is also valid if the V d is negative; that means, in reverse bias condition. If the V d is higher and if it is becoming comparable with V T of course, this will be deviating from this number. But just to get a since of what is the value of this resistance of this resistance which is reciprocal of this. So, which is V T divided by I naught it is 26 millivolt divided by 10 to the power minus 13 in this case right.

So, which means that it is 26 into 10 to the power 10 ohms, that is very very high. So, we can say for all practical purposes in reverse bias condition it is very high. Even, if say diode voltage is say positive, but as long as it is less than this cutting voltage, then also we may say that this resistance it may be remaining in the order of tens of mega ohms. So, that is the; that is the circuit model. And, as I said that this two representation of the diode is essentially we do have exponential equation is getting replaced by piece wise linear model.

So, we do have cut off region and then we do have the ok. So, let me we do have the “on” region and we do have the cut “off” region here. So, based on these two pieces we can simpler simplify the circuit. So, let us see how this piece wise linear model can be practically used for the previous example circuit.

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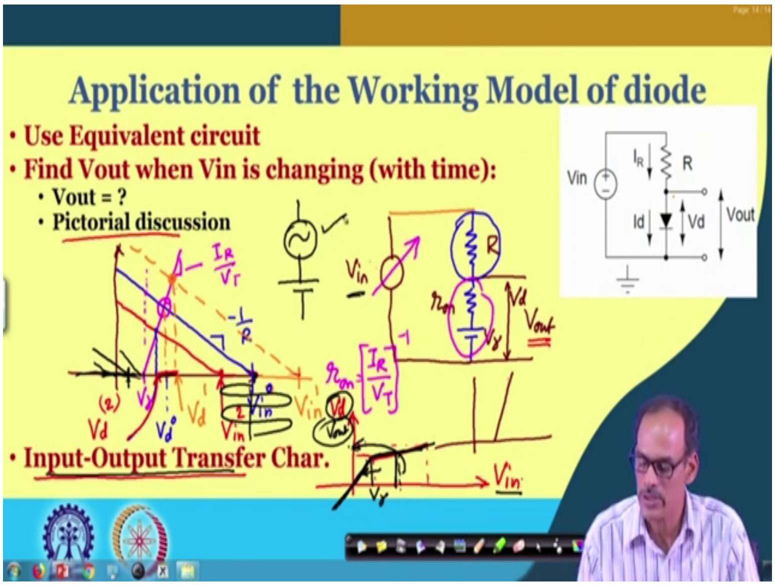

So, let us see the as I said let us see the application of this simple model. Let me redraw this circuit by replacing this diode assuming this V in is higher than cutting voltage and hence the diode is in on condition. So, the diode it will be replaced by the equivalent circuit in on condition.

So, we do have the V in here connected across this diode and we call this is V out. In fact, we call this is cutting voltage and the voltage drop across the series connection namely; V gamma n drop across this on resistance r on together it is nothing, but the diode voltage and this is the r.

So, you may say that the this behavior, this part is essentially diode it is getting replaced by piece wise linear model, essentially this piece wise linear model. So, now, if I replace this diode characteristic in this form. So, how do I find the solution? Instead of going through this iterative method can I get even a straight forward, you know straight forward single step method.

So, here again we may say that I do have pull up element and it is characteristic is given here, and the voltage here it is V in slope here it is 1 by R with a minus sign. And, then if I say that this characteristic lower element characteristic it is nothing, but this one, where this part is V gamma. Now, if I know this slope then it will be well and good, but in case if we do not know probably, you can assume that this is V gamma and then you can find the corresponding current here, and from that using that I d current you can calculate this r on equals to whatever the current will be getting here, say I R divided by V T inverse.

So, that gives you the slope here. So, that is whatever the I R you will get divided by V T that will be giving you the slope. So, if you know this point if you know this slope then you can find the intersection point of the 2 linear lines. So, that is how the this equivalent circuit it can be used? Now, next thing is that how do I use this simple model in case this input voltage is changing with time and using the same you know equivalent circuit.

So, if this voltage it is say getting increased to some other this input voltage it is getting increase, we can say that slope remains the same, but then the corresponding pull of characteristic or rearrange characteristic, it is getting shifted up and we may say that this may be new V in call V in 1, this may be V in 0. So, and now the intersection point is getting moved up here and the corresponding output voltage instead of this one. Now, it is getting change to whatever V out or V d whatever you say it is going to V d 1 from the previous one it was V d 0.

So, likewise if the they V in it is changing to some other value, say lowered value with respect to the previous V in, the corresponding the cutting point of the pull up characteristic, rearranged characteristic. Now, it is shifted to some lower value call V in 2. So, now, we do have V in 0 V in 1 and V in 2. So, the corresponding output here it will be V d 2 and all these V ds are essentially same as V out.

So, now for different values of this V in if I try to see what will be the corresponding V d or V out what I will be getting is input to output transfer characteristic. And, if you see here pictorial view as I say that pictorial discussion. So, if I change this V in from say this value to this value and this value, what I am getting is the corresponding V out or V d it is changing slowly.

So, if you see that the amount of change here it is very small compare to whatever the changes are there. So, even though V in is changing over a wide range, the corresponding output change or V d change it is very small, that is mainly because slope of this line it is very high. In fact, theoretically if I say that if this line it is vertical, this line it will be horizontal indicating that if r on it is 0 at the output you will get only V gamma.

And, so you can say that input or output characteristics is like this, but it will be this transfer characteristic it is valid as long as the diode it is in, the diode it is in on region. So, if the voltage in the input voltage if it is less than V gamma on the other hand then load line or you can say the pull up characteristic it will be like this and then the it cuts the diode characteristic at this point. So, if we change this V in now say instead of this one if you are changing the V in here and so and so, the corresponding V out will also be equally changing.

So, in other words if the V in it is less than say V gamma then input and output they are having the same value. So, the input to output transfer characteristic of the circuit so, if I so, this V d is nothing, but as I said V out. So, input to output transfer characteristic it is having 2 segment one is this one another is this one. This is mainly coming because of the 2 pieces of the diode characteristic. And, this part it is very small having very small slope depend representing the high slope of this line and this is having fairly good slope.

So, that is the input to output transfer characteristic you can say. Now, having said that if this voltage it is changing with time, we may be having different way of changing this voltage. So, you may say that this voltage may be having a d c value and then it may be having the variable part.

So, which means that we may keep the dc voltage may be somewhere here and then we may vary this input with respect to that. Either may be in sinusoidal form or it may be triangular form or whatever it is. And, then the corresponding output whatever the output you will be getting that can be directly obtained from this transfer characteristic. In other words that using this input to output transfer characteristic, you can find what will be the input to output relationship.

So, that is what will be discussing now instead of varying this input voltage arbitrarily and may be over a wide range. If you rested this variation within this range and if the in the variation is having certain pattern, then you can say that this linear segment it is also say is suggesting that at the output you will also be getting the similar kind of pattern without having much distortion.

On the other hand if the variation it is large enough and if the diode is entering into the other region of operation, then of course, the signal at the output it may be having getting distorted because of the highly non-linear nature. So, for the time being let you consider situation where this signal variation it is getting restricted over this linear range.

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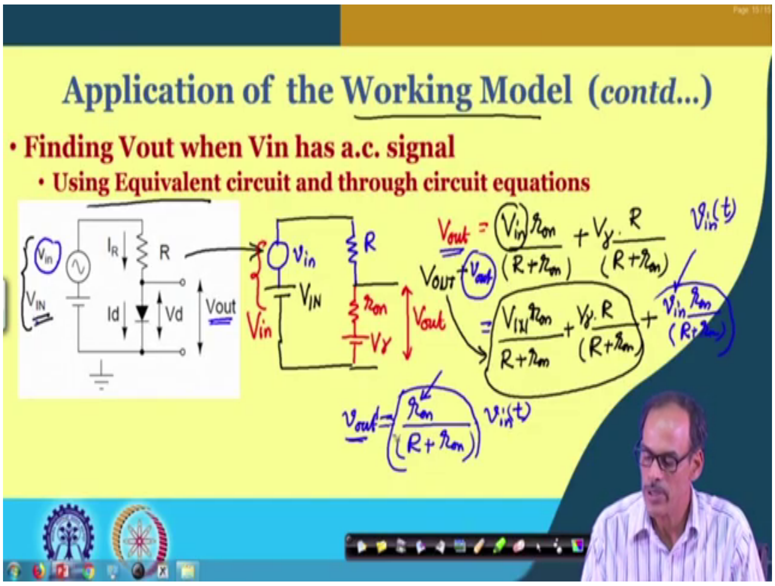

So, let you move to the corresponding example, where the input voltage. Basically, this is the same circuit. Now, we do have the input it is combination of it is having combination of dc part namely capital V in and then the small signal part. So, we do have the small signal part here.

So, as you can guess that if I analyze this circuit you will also be finding the corresponding V out, which will be having 2 component; one part is corresponding to dc part, another part it is corresponding to small signal part. So, before we go into the actual expression, let me redraw this circuit namely replace this diode by the corresponding equivalent circuit.

So, we do have the small signal we do have the dc part and then we do have the pull up element and then we do have the diode part. And, this diode part it is having cutting voltage in series with this r on. So, this is I should say equivalent circuit. So, now we can say that the actual circuit is getting converted into equivalent circuit and where what you are doing is this model whatever we say this working model we are using for the diode.

So, we do have R here same R and we do have the r on here we do have V gamma. Now, if you analyze this circuit if I consider this two together it is V capital in having both dc part and the small signal part, and if you see what is the corresponding output. I think you yourself can find that V out equals to it is having V in multiplied by r on divided by capital R plus small r on plus V gamma into R divided by capital R plus r on.

Basically, you are finding this output voltage by super position theorem by considering this one first making this is 0 and with the second part is making this part 0 and your giving this V gamma. Now, within this V in as I said that it is having both dc part and the ac part. So, if I rewrite this portion in terms of this capital V in and then small signal part small v in what will be getting is we can say that, this is V in r on divided by R plus r on plus V gamma into R divided by R plus r on. In addition to in addition to we do have v in r on divided by R plus r on.

So, this part you may say that this part it is coming from the dc part and the cutting voltage of the diode you may say that it is not changing, but this part probably it is changing with time and probably it is carrying a signal. So, this v in may be function of time.

So, this V out you may say that it is having 2 parts namely V out capital plus small signal v out. So, this small signal v out it is basically this part. So, we can see that capital V out or dc part is having this expression and the small signal v out small v out is r on divided by capital R plus small r into v in.

So, you may say that this part it is transfer function of the system, which is transforming this input may be in time domain this is also may be in time domain, but whatever it is the signal it is getting reflected to the output. And, if you are not changing this point this operating point, you may say that the corresponding r on practically remains constant.

So, we may say that the gain of this circuit remains constant. So, let we see the corresponding input to output transfer characteristic curve and let we reinterpret what are the things are there, please remember that this small signal part and then dc part in the next slide.

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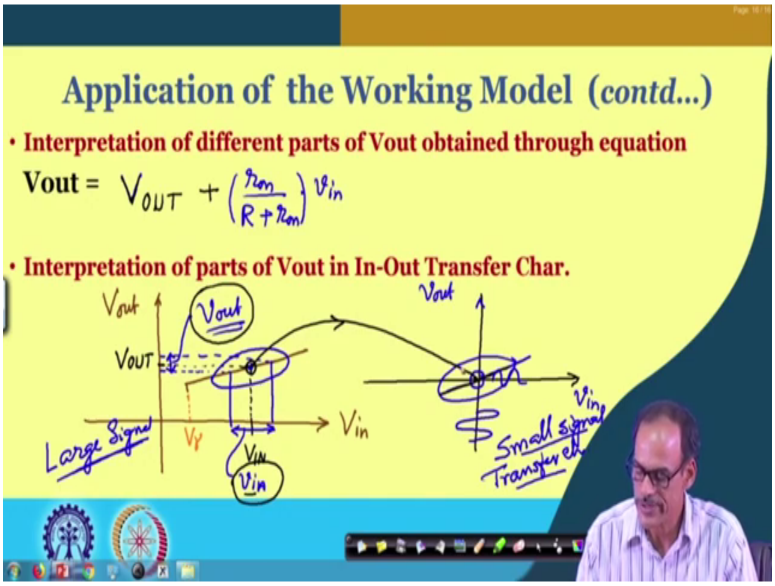

So, let me rewrite this V out part. So, we do have V out is having dc part. I am just simply denoting this is V OUT. So, you may assume that this is function of capital V in and V gamma and so and so and in addition to that we do have the small signal part, which is r on divided by capital R plus small r into v in right.

So, this is what we already have now? What is the interpretation in the transfer characteristic curve? So, you may recall that in the input to output transfer characteristic curve. If, I say that this is the V in having both dc part as well as the small signal part and along the Y axis we do have the V out, and we say that the transfer characteristic curve it is fairly linear may be having a small slope. As long as this is not exceeding this V gamma voltage, then we are safe. And, if I say that we do have V in probably V capital IN with respect to that we are applying some small signal V in.

So, over that with respect to capital V IN we are applying v in and changing this and the corresponding V in. What is the consequence here? At the output corresponding to V IN you are getting V capital OUT, which is of course, it is function of V IN and R and then r on and V gamma and so and so.

And, in addition to that what you are getting is because of this small signal applied at the input we are also getting corresponding output. So, you may say that here we are getting small signal output and this small signal output it is given there.

Now, many a times for analog circuit we may be keeping this point this dc part constant. In other words we like to keep this point constant and then we like to apply this as signal. So, it may be sinusoidal it may be non-sinusoidal or whatever it is and we like to keep our concentration only over this range. So, if you vary the signal here you will be getting the corresponding output here. And, we like to see the relationship between the small signal input to small signal output.

So, what does it mean is that, our main interest for analog circuit instead of really seeing this much of dc shift and all we maybe rather more focusing on v in to v out, small signal v in to v out characteristic curve, which means that we are basically concentrating on this part. What is this part? This part of the input to output transfer characteristic curve, it is getting shifted to the origin of this new graph. So, we can say that operating point is getting shifted to the origin of this characteristic curve. And, the line segment it is getting retained, it is retained.

Now, this characteristic curve. So, here if I apply input signal naturally I will be getting the corresponding output here ok. So, here while we are retaining the dc part it is referred as large signal input to output transfer characteristic curve and this is referred as small signal transfer characteristic curve. So, what is the, what is the advantage here? First of all this characteristic curve it is not going through the origin whereas, this is going through the origin. And, we are keeping the circuit in fact, the analysis probably simpler because we are dropping the dc part ok.

So, this whatever the translation of the characteristic curve from large signal to small signal, it is circuit wise it is you may say that the original circuit we are representing by another equivalent circuit call small signal equivalent circuit. So, this translation of de transfer characteristic curve is basically circuit wise representing the circuit in a even a in a simpler form. So, let see what is that simpler form?.

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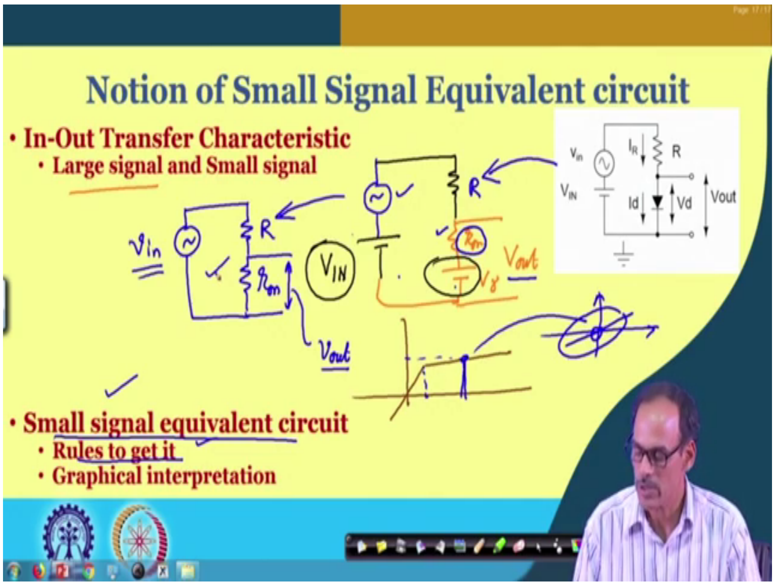

So, now we do have something some notion call small signal equivalent circuit. So, to start with we do have the signal in series with the dc part and then we do have the register, we do have the diode part, along with the cutting voltage and then we are completing the circuit.

So, this is what we said it is the large signal equivalent circuit consisting both V gamma and r on. Now, whenever we are talking so, this is the large signal. Now, let us see what is the small signal? So, in small signal what will be doing is that we will retain this part; we will retain this part and the dc part. So, whatever you say V IN V capital IN, we like to remove it, we like to remove this one, we like to remove this one and we like to retain only this one.

So, the left out circuit what will be having here it is the signal part the same register R and then we do have the r on and the corresponding V gamma it is completely dropped, this is v in and whatever the corresponding output will be obtaining here note that this is small v out. Here, we are having capital V out containing both dc as well as AC whereas; here we do have only small signal part.

So, this is referred as small signal equivalent circuit and as you can see here, what is the what are the rules? The dc part we are making it 0, the dc voltage whatever even though it is coming from the you know device we are dropping to 0. And, the rest of the things we are retaining and we are retaining of course, the small signal part.

So, that is the rule. And, graphical interpretation what we said it is translating the large signal transfer characteristic curve to different graph and transfer characteristic curve it is going through origin. This is very vital point that it is going through the origin, which means that this circuit is basically representing linearize version of the original circuit. Even though this circuit it is non-linear, but whatever the characteristic we are getting and the equivalent circuit we are getting here it is nothing, but linearization.

So, whenever we are talking about small signal equivalent circuit I should say that it is linearization of the large signal equivalent circuit. Now, we do have whatever we have discussed is that the original circuit from that we obtain large signal equivalent circuit, this large signal equivalent circuit it will be helping us to find the operating point. And, in fact, that operating point helps us to find the value of this R on.

So, definitely that is important also we have to check whether we are in the linear range of large signal characteristic. Probably you can find what may be the limit up to which this linear characteristic is valid and then we move to small signal. So, it is having importance large signal equivalent circuit it is having importance, but once you are very sure that this point it is a good point and then better we translate to that the entire circuit in to a small signal equivalent circuit or linearizing the circuit.

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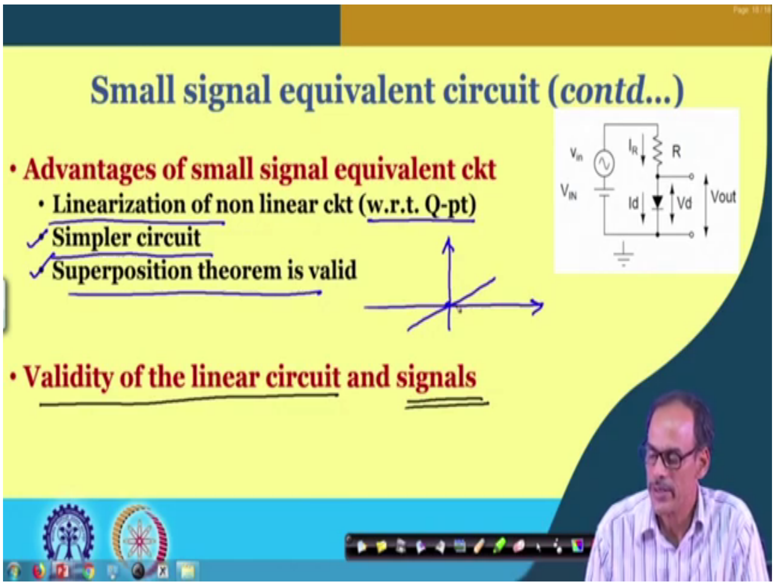

So, as I said that we are linearizing the circuit and we have enlisted what are the different advantages. Note that we are linearizing non-linear circuit with respect to the operating point or quiescent point. So, first we find the operating point and then we are basically linearizing the circuit. So, it is expected that once you linearize probably the obtain circuit is simpler we already have seen that.

And, most important thing is that this will simplify the analysis and the other vital point is that since the input to output transfer characteristic it is going through the origin of our small signal transfer characteristic. So, super position theorem it is valid and that is very vital to simplify circuit whenever we do have multiple signal sources. So, these are the important advantages.

And, that is why for analog circuit we always do find the non-linear circuit, then we move to small signal equivalent circuit or linearize circuit. And; however, you need to be very careful word of quiescent that validity of the linear circuit we have to be maintained. And, the signal level should be such that we should restrict our you know voltage and currents within the linear range of operation. I think what you can do it is probably you can try to take this numerical problem, and you can try to solve this.

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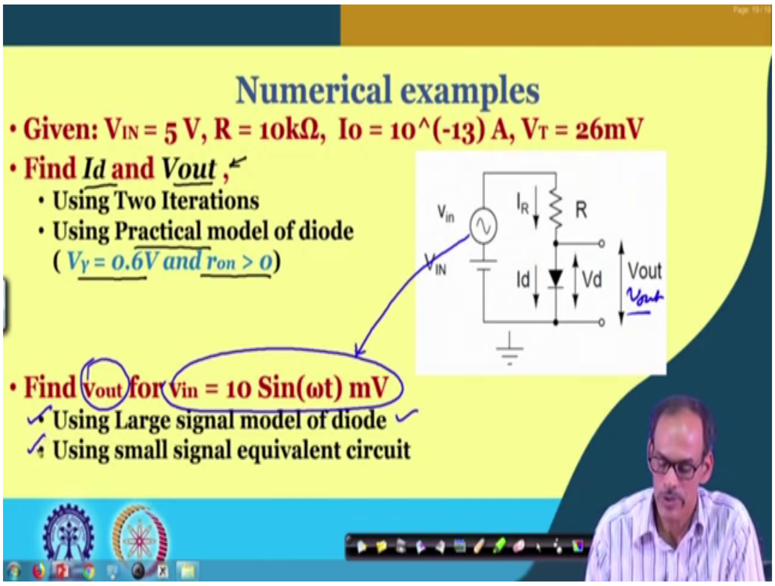

So, I have frame this numerical problem slightly I have change this voltage and rest of the things I have kept as is. So, what you have to I think you yourself can find. So, you need to find this I d and V out by iterative method we already have discussed. And, also practical model method considering V gamma equals to 0.6 volt and r on probably can calculate the value of r on which is non-zero. And from that you can find what will be the corresponding V out, of course that will be slightly different from V gamma.

And, then you can draw the small signal equivalent circuit you can find the small signal V out, so this is small signal v out, for small signal input voltage here. So, this small signal input voltage it is given there you need to find what will be the corresponding small v out? So, there may be 2 approaches; one is directly you can use large signal model, you will be finding that it is bit tedious even though it is simplified model of the diode has been use there and then you can see how easy to use the small signal equivalent circuit?

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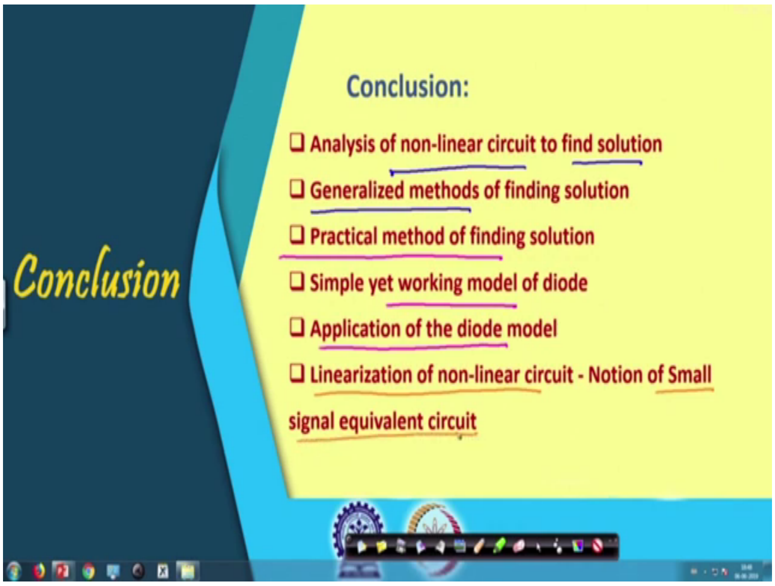

So, in this part of our discussion what we have covered it is basically we are analyzing or we have analyze non-linear circuit, diode circuit as an example to find it is solution. We have discussed two generalized method one is in fact, both of them are essentially same one is pictorial representation and where we have discussed how to rearrange the pull up characteristic to you know get it suitable in combining form with a pull down part.

And, then the method of the iterative method of finding the solution, then in the second part we have gone into the practical method of finding solution. Namely, using you know guess and solution one step solution, which suggest that it is better to use some simpler model, working model of the diode namely piece wise linear model.

And, that model we have discussed to with the same diode circuit and then we have gone into you know linearization of the circuit. Basically non-linear circuit we can linearize and we have discussed about a notion call small signal equivalent circuit and it is how we obtain the small signal equivalent circuit. I think that is all I do have now so, I think we will be moving to the next topic in the next class.

Thank you.