Electrical Distribution System Analysis
Dr. Ganesh Kumbhar
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture – 06
"K" Factors and their Applications

Dear students, welcome to the 6th lecture of the course electric Electrical Distribution System Analysis. This is the first lecture of chapter 2nd, which is basically approximate methods of distribution system analysis. Before going to the chapter 2, we will just see what we have seen in chapter 1. In chapter 1 there were 5 lectures, in lecture number 1 we have seen various structures of the distribution system. Basically, we have seen distribution system is classifies into primary and secondary distribution system.

Then we have seen why we need to study distribution system analysis and then finally, we have seen content of this particular course at the end of lecture number 1. In lecture number 2 we have seen various substation components starting from isolator, potential transformer, current transformer, circuit breaker transformer, bus bar arrangements. In lecture number 3 we have seen various components of the feeder, we have seen voltage regulator, we have seen feeder configurations like single phase feeder, two phase feeder or three phase feeder. Then we have seen there might be underground cables, then there might be sectionalizer switches, capacitor bands and all other components related to smart grids.

In lecture number 4 we have seen nature of loads; in that lecture we have studied various different kinds of load curves of different types of consumers. And we have studies various different factors like demand factors, load factor, diversity factor and utilization factor. And in lecture number 5 we have seen load allocation at the substation level, that is distribution transformer or feeder level. Then we have measurement at the substation level, then we can allocate these loads at distribution transformer and feeder level.

Now, let us go to the approximate methods of analysis. If you do actual distribution system analysis, we have seen that in distribution system lines are actually untransposed as well as loads are unbalanced. And we have seen that these loads might be of single phase, two phase or three phase in nature and transmission lines also might be single phase, two phase or three phase. And if you want to do the distribution system analysis exact modeling of all these loads as well as feeder components, which might be single phase, two phase or three phase we need to do detailed modeling. However, many times in the field distribution engineers need approximate or quick kind of solution.

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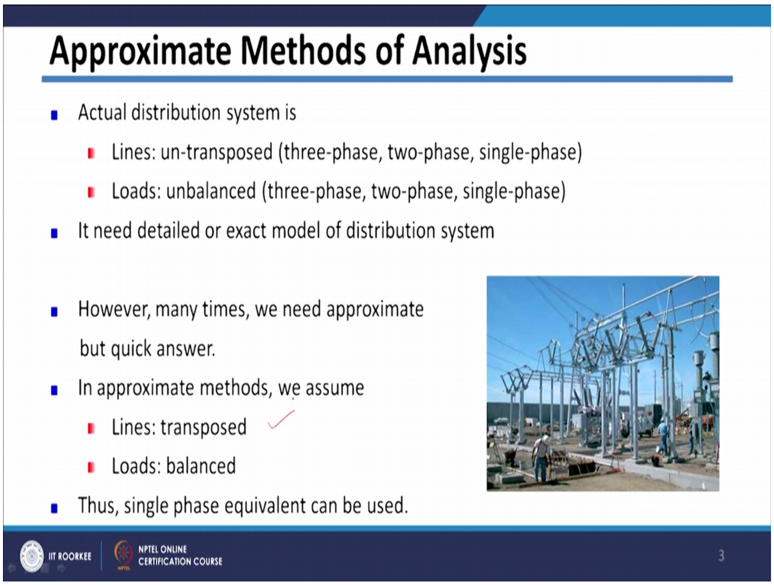

So, what we are doing in approximate method we are assuming that loads are balanced and lines are transposed. So, with this approximation we can use single phase equivalent of your feeder as well as loads for the analysis. Let us see simple example where we want to calculate voltage drop and how we can approximate this voltage drop.

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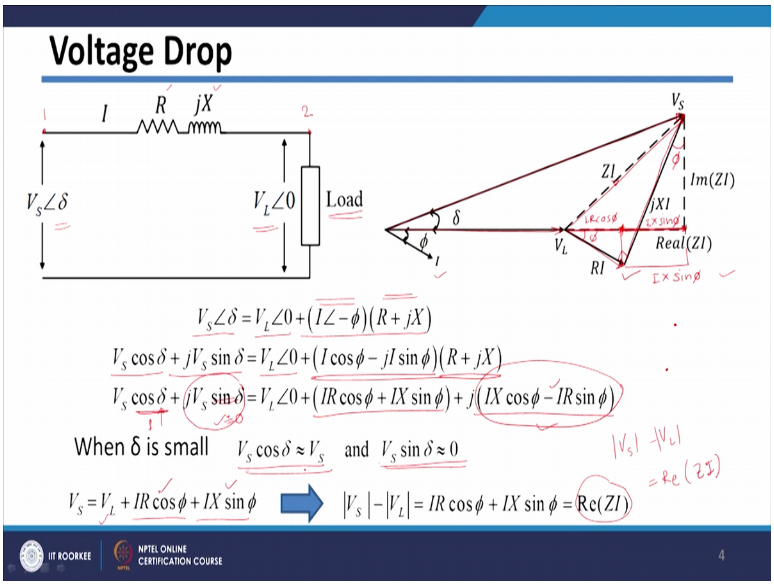

Let us see this figure what I have done it here you have this feeder component from say point 1 to point 2, which is having resistance of R and reactance of jX. And then there is load which is having say lagging power factor voltage at load end is actually V L angle 0 and voltage at sending end say V S angle delta

Now, if you plot the factor diagram or phaser diagram of this particular circuit it is shown in this particular figure. So, since V L is having angle 0 so, you have this V L vector here. Then if you add resistive voltage drop across the feeder so, this will be resistive voltage drop which will be in phase with current current phaser. And then the voltage drop across your reactance will be with 90 degree with respect to your current and if you add V L plus RI drop plus jXI drop we will get voltage at the sending end terminal which will basically this voltage V S.

Now, if you do exact analysis your V S voltage that is V S angle delta will be real angle 0 plus voltage drop across your feeder component, that is R plus jX which is feeder impedance multiplied by current which is drop, drop across the feeder. Now, if you can write in terms of rectangle coordinates this V S angle delta can be converted into V S cos delta plus jV S sin delta; V S angle 0 as it is I kept because it will not the having imaginary part. Then this I with phase angle minus phi we can say I cos phi minus j sin I sin phi and then there is impedance.

Then if you multiply them and take the imaginary and real component together of this particular quantity a real components will be IR cos phi plus IX sin phi. An imaginary component will be IX cos phi and IR sin phi minus IR sin phi. Now, we know that in case of distribution system your angle delta will be having very small value. So, if the delta is small your cos delta will be approximately equal to 1 and your sin delta will be approximately equal to 0.

So, in that case your imaginary component on left hand side and imaginary component on right hand side they will be negligibly small. So, therefore, in case of delta which is small we can say V S cos delta will be equal to V S approximately equal to V S. And then V S sin delta will be approximately equal to 0, where these imaginary components are negligible. In that case your V S will be equal to V L, which is having a only a real part and then IR cos phi plus IX sin phi.

Now, if you observe IR cos phi. So, you are having this IR phaser here and then you are having this angle phi and this will be your IR cos phi length we up to this one. And then if you see since this and IR and IX they will be at 90 degree, this angle also will be phi. In that case this becomes your IX sin phi so, this this is same length so, this also will be equal to IX sin phi. So, you can see that IR cos phi plus this IX sin phi becomes equal to real part of your phaser Z multiplied by I.

So, if you see the real part of Z multiplied by I it will be IR cos phi plus IX sin phi. Therefore, this IR cos phi plus IX sin phi we can write it as a real ZI. Therefore, voltage drop we can see approximately we can write V S minus V L which is voltage drop between the two terminals, which will be equal to real part of Z multiplied by I.

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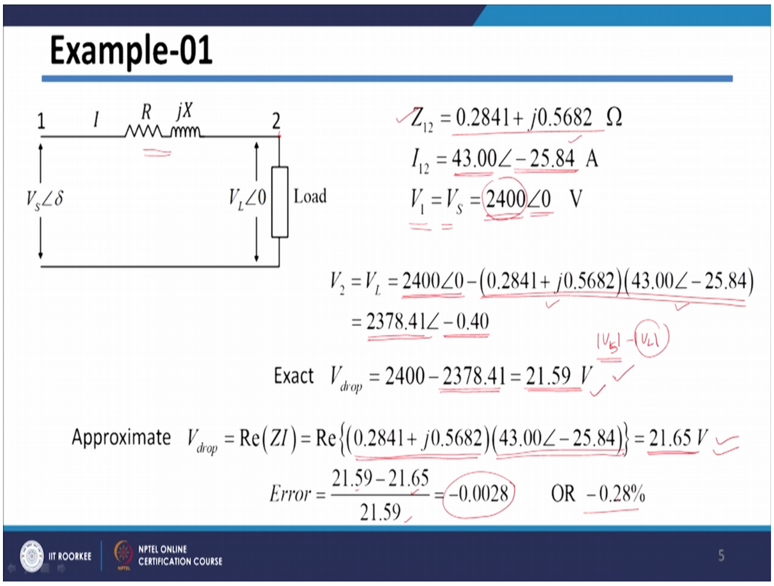

Now, let us check how much correct this approximation is. So, in that case we can just assume some values for different components of this distribution system. Let us say Z 12 is impedance of the feeder which is given by this value. Then let us say current which is flowing through the feeder is having 43 ampere with lagging power factor of 0.9. So, therefore, phase angle will be minus 25.84 and if you see the voltages voltage are sending and I am assuming it is 2400 with angle 0 degree. So, if you calculate V L that is voltage at terminal 2 it will be 2400, which is voltage at primary end minus voltage drop across your feeder section which is this is your impedance multiplied by current so, Z multiplied by I.

And if you calculate exact drop so, voltage at secondary terminal that is 2 is 2378.41 with very negligibly small angle delta. So, if you calculate a drop from it here which is V L V S minus V L. So, your V S is 2400 magnitude we want to take minus your V L is 2378.41. So, exact voltage drop is actually 21.59. Let us say approximate drop we already seen approximate voltage drop is real part of Z multiplied by I.

So, say real part your Z is impedance which is given then current we are calculated or which is given 43 amperes. And then from this if we calculate real part of real multiplied by which comes around 21.65 volts. Now, if we calculate error so, error will be equal to this value, minus this value this is real exact value and this is approximate value and if we calculate error from this so, exact value minus approximate value divided by exact value. So, error comes around minus 0.0028 which is very small which is just 0.28 percent. So, you can see that we can use real part of ZI as a voltage drop for realistic analysis of distribution system.

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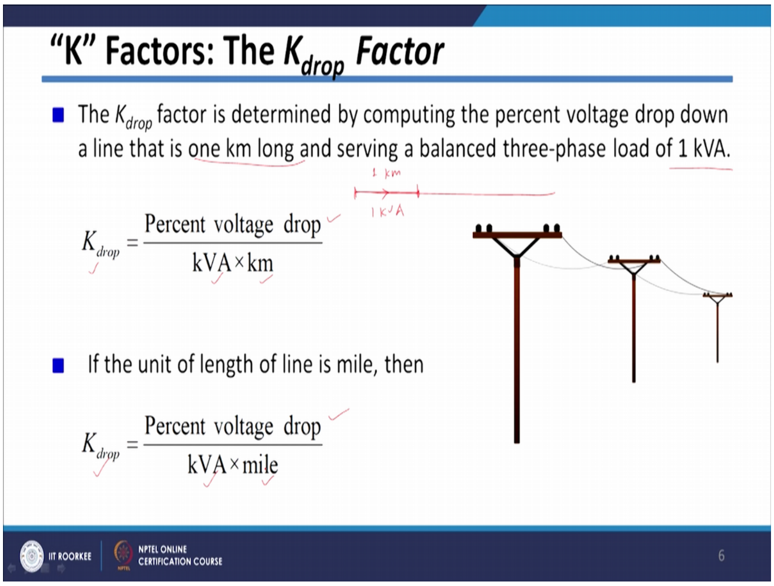

Now, come to the K factors. There are two K factors, one is called as K drop factor and another is called as K rise factor. Now, K drop factor is nothing, but percentage voltage drop across your feeder which is of 1 kilometer length long, 1 kilometer long and serving 1 kVA load. So, if you are having feeder section and if you are passing a 1 kVA of power through this and if the length is 1 kilometer ok, then percentage drop, which is happening across this length is called as your K drop factor. So, K drop factor in that case defined as percentage voltage drop per kVA per kilometer.

If your length of feeder is in miles then you can write K drop factor will be, percent voltage drop divided by kVA and in that case it will be mile. So, percentage volt percent voltage drop per kVA per mile.

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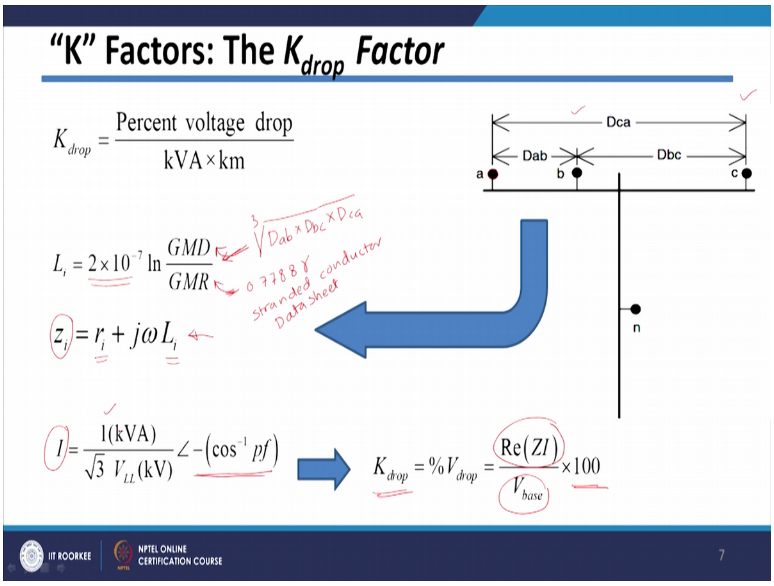

Let us see how to calculate this K drop factor for a particular feeder section. Let us say your feeder is having geometry which is shown like this in the figure, where a b c are the conductors and these are the distances which are shown. So, by knowing these distances we can easily get your inductance of the feeder which is just 2 into 10 raise to minus 7 natural log of GMD by GMR, where we know that GMD is nothing, but cube root of all the distances that is Dab multiplied by Dbc multiplied by Dca.

And if you take the cube root of this will give you GMD and GMR is nothing, but of particular conductor which is nothing, but if it is single conductor GMR will be equal to 0.7788 into your radius of the conductor. However, if the conductor is standard kind of conductor then you can get the GMR from the data sheet of data sheet of the conductor. Once you get the inductance you can calculate the impedance of the conductor for 1 kilometer length by knowing the resistance of the conductor and inductance of the conductor.

This will be impedance of 1 kilometer, then we can calculate current for 1 kVA loading. So, current for 1 kVA loading will be 1 kVA divided by root 3 into line to line voltage and its angle will be minus cos inverse of power factor. And therefore, once you get the current for 1 kVA load and impedance for 1 kilo meter length feeder section, we can get the K drop factor which will be real part of ZI divided by your V base multiplied by 100; which will be percent voltage drop for 1 kVA load and 1 kilometer length feeder.

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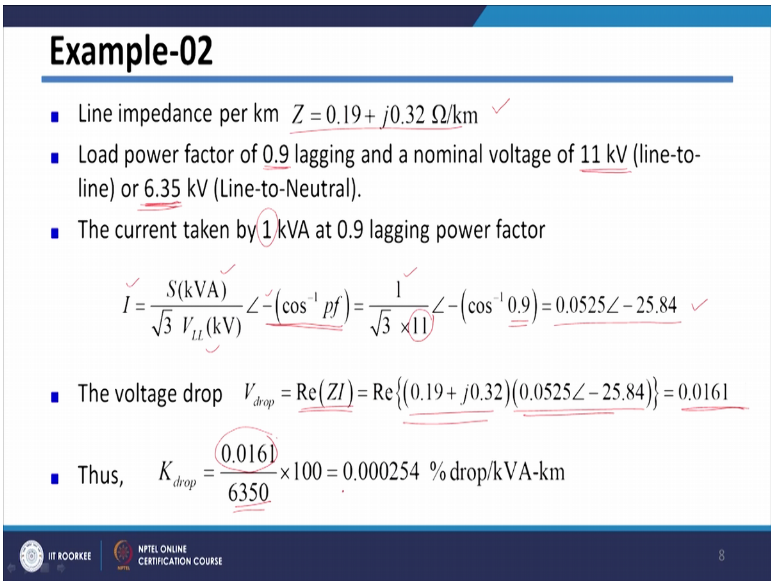

Let us see for a simple feeder, how can we calculate this K drop factors. Let us say you are having impedance of the feeder which is given here, Z is equal to 0.19 plus j 0.32 ohms per kilometer which is impedance per kilometer. Let us say power factor of the load is 0.9, nominal voltage of the feeder is 11 kVA line to line, in that case your line to neutral voltage will be 6.35 kV then current taken by 1 kVA at 0.9 lagging power factor.

So, we are calculating current for 1 kVA load. So, we know that current will be power divided by root 3 into V LL and its angle will be cos inverse of power factor and minus sign, since it is lagging. So, 1 kVA load and then voltage is line to line 11 kV and your power factor is 0.9. If you put those values into this equation we will get value of current, we know the value of current at 1 kVA load, we know the Z for 1 kilometer. So, in that case voltage drop for 1 kVA load and 1 kilometer feeder we can calculate that is read real part of your Z multiplied by I, Z is given I is calculated.

So, your voltage drop will be 0.0161, for K drop factor we need percent voltage drop. So, to get the percent voltage drop we need to divide this 0.0161 by base voltage. So, base phase voltage is 6.35 kV so, we can put it here. So, K drop factor in that case will be 0.000254 percent drop per kVA per kilometer ok.

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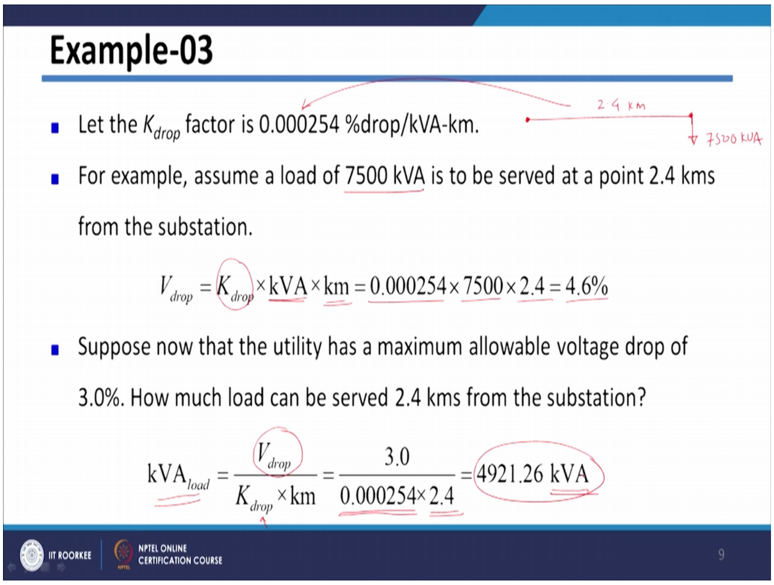

Let us see the application of this K drop factor. Let your K drop vector is 0.000254 percent drop per kVA per kilometer. Means, you are having say feeder of 2.4 kilometer and the K K drop factor of this feeder is 0.000254 and this feeder is supplying a load of say 7500 kVA.

And I want to estimate the voltage drop which is happening in this particular feeder session. So, we can get this voltage drop very easily, it will be your K drop factor multiplied by kVA multiplied by kilometers. So, K drop factor kVA 7500 and length is 2.4 kilometer, which will give me 4.6 percent of voltage drop. And normally, we know that there is maximum allowable voltage drop limits and many a times it may be plus minus 3 percent, plus minus 5 percent or plus minus 10 percent.

Let us say for this particular utility your voltage drop limit is plus minus 3 percent and I want to restrict the load such that this limit will not get violated. Now, I want to find out how much load I can serve without violating this 3 percent limit over this 2.4 kilometer feeder; that can be easily calculated here. So, load that can be served without violating limit of 3 percent so, voltage drop limit is now 3 percent. So, V drop I can put 3 percent, then K drop factor of this feeder we know which I put it here 0.000254 and length of the feeder is 2.4 kilometer.

And from this we can easily calculate maximum kVA which can be served by this feeder which is 4921.26 kVA, if the kVA is more than this your voltage limit will get violated. So, you have simple applications of your K drop factor wherein, one application we have seen how to calculate voltage drop for different kVA's and different kilometer length feeder. Another application we have seen, if there is maximum allowable voltage drop limit we can also calculate how much kVA we can serve on this particular feeder.

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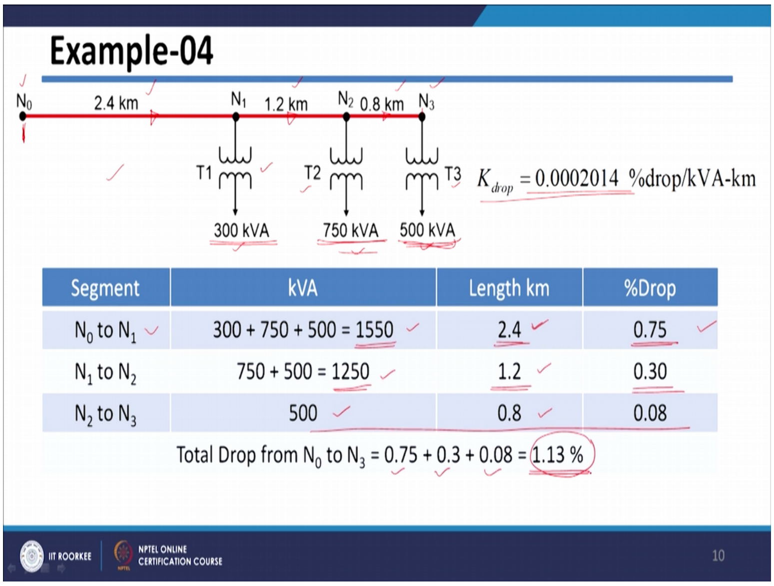

Let us take one more example like I shown it in figure of this particular feeder which is ranging from node N 0 to N 3, it is serving three loads with three d distribution transformer T 1 T 2 and T 3. The lengths of different feeder sections are mentioned here. So, first feeder section 2.4 kilometer, 1.2 kilometer and 0.8 kilometer and three loads are 300 kVA, 750 kVA and 500 kVA and let us say K drop factor of this particular feeder is 0.0002014 percent.

And one I want to calculate the total drop from point N 0 to N 3, if loading of my feeder is as given in this particular figure. This can be calculated as shown. So, for different feeder section from N 0 to N 1 we can see that whole load is flowing from N 0 to N 1, that is a total loads flowing from feeder in section N 0 to N 1 will be addition of all the three loads. Then load or power which is flowing from N 1 to N 2 will be addition of this two load that is 750 and 500 kVA which will be 1250 kVA. And in third feeder section only load which is flowing is 500 kVA.

So, this gives us loadings of three different feeder sections, length of first feeder section 2.4, second feeder section 1.2 and third feeder section 0.8. Then we can easily calculate voltage drops in all the three feeder section. In the first section it will be K drop factor multiplied by kVA multiplied by your kilometer will give me drop in first section in second section again K drop factor multiplied by your kVA multiplied by your distance that is 1.2 kilometer which will give drop in second.

Similarly, I can calculate drop in third section and then if you add drops in all the three sections I will get total drop in the feeder section from N 0 to N 3. So, drop from N 0 to N 3 will be 1.13 percent. So, this is the application of K drop factor, let us see what is called as K rise factor. So, in case of K rise factor it is basically applicable whenever, we are connecting capacitor banks in your distribution system.

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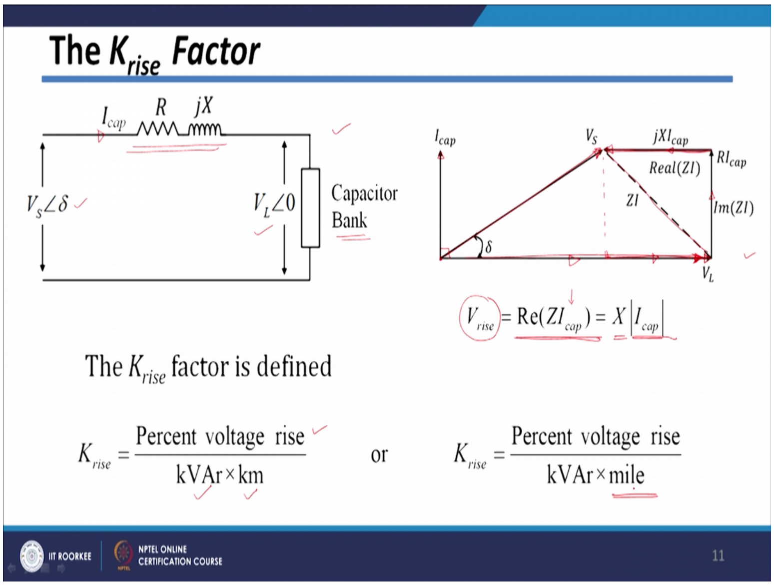

So, let us see this particular figure. So, in this case also we are having the sending end and receiving end voltage which is V S angle delta and V L angle 0, then feeder impedance. And in this case your capacitive current flowing because I am considering at the end there is capacitor bank. Now, if you analyze this circuit we can see that the phasor diagram of this few circuit is shown in the figure on the right-hand side. So, this is your vector V L or phaser V L and if you add two voltage drops, that is voltage drop across the resistance and voltage drop across the reactance I will get voltage V S. So, in this case since it is capacitive load your capacitive current will be leading with respect to your V L.

So, angle between V L and capacitive load will be 90 degree. So, in this case also we can easily see that your real part of ZI will be nothing, but your voltage drop. So, voltage drop or in this case since your V L which is voltage at the capacitor end is more than voltage at the sending end. We instead of calling voltage drop, we can call it as a voltage rise which is again real part of Z multiplied by your current I, in this case it is capacitive current. And if you observe this figure a real part of Z multiplied by I, real part of this is nothing, but your this vector which is again exactly equal to your X multiplied by I cap.

So, your voltage value will be X multiplied by I cap. So, K rise factor is defined as percent voltage rise because voltage is raising here, per kVAr of the capacitor per kilometer. So, voltage rise percentage voltage rise per kVAr of capacitor per kilometer, if your distance is in mile it will be percent voltage rise per kVAr per mile.

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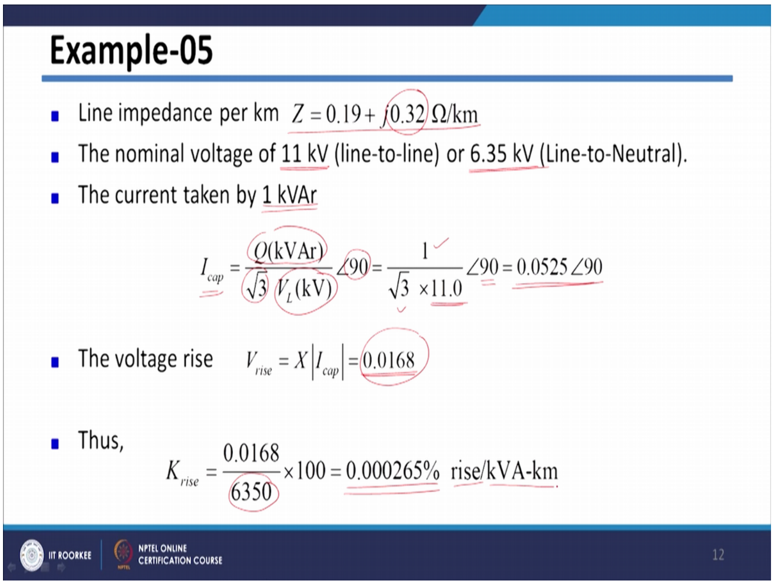

Let us say impedance of your line is Z is equal to 0.19 plus j 0.32 ohms per kilometer. Nominal voltage of your feeder is 11 kV therefore, phase to neutral voltage or line to neutral voltage will be 6.35 kV. And in this case we want to calculate current taken for 1 kVAr load because we want to calculate K rise factor which is basically percent voltage drop per kVAr per kilometer. So, to get current per kVAr we need to calculate current for

1 kVAr. So, in that case your current will be given by this equation this is nothing, but your power divided by root 3 into V LL and in this case since it is on the capacitive current your angle will be 90 degree.

So, kVAr is 1 kVAr root 3 and then voltage is 11 kV line to line angle is 90 degree. So, if you calculate this your capacitive current will be 0.0525 and its angle will be 90 degree. Then you can easily calculate total voltage rise, total voltage rise will be X multiplied by I cap. So, in this case we want I cap magnitude I cap magnitude is basically 0.02 0.0525 multiplied by X is 0.32.

So, if you multiply them you will get voltage rise which is 0.0168 and then K rise factor will be percent voltage drop. So, you need to divide this by base voltage that is 6350. So, it will be K rise factor will be 0.0168 divided by 6350. So, if you do that your K rise factor will be 0.000265 percent that is in this case I am saying percent rise per kVA r per kilometer.

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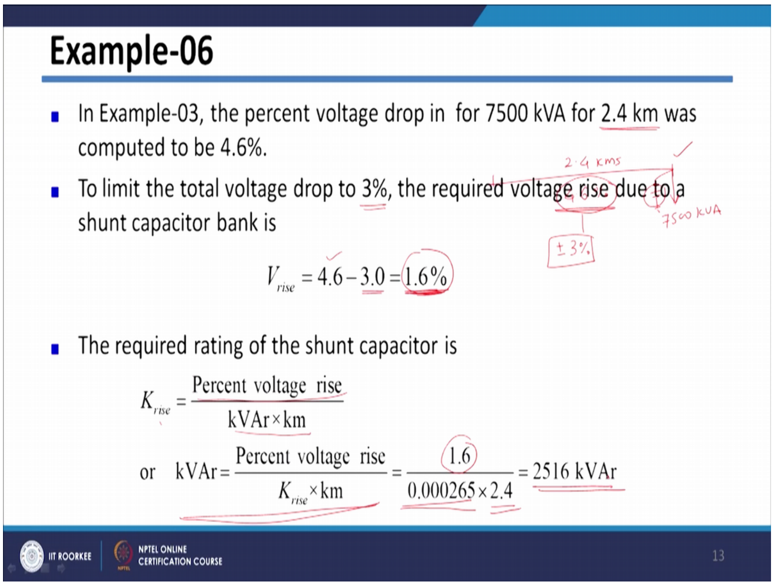

Now, let us take one example where we as for example, 3 we have seen that percent voltage drop for 7500 kVA load for 2.5 kilometer means, for this particular feeder length of 2.4 kilometers and which is supplying 7500 kVA of load; we have seen that the computed voltage drop is around 4.6 percent. Now, what we want to do? We want to actually decrease this voltage drop by putting some capacitor across this load. And I want to calculate the value of this capacitor such that this voltage drop will be under the limit which is we have seen that plus minus 3 percent. So, by putting the capacitor across this load we want to increase the voltage so that the percentage voltage drop will be in limit of plus minus 3 percent.

So, to limit total voltage drop to 3 percent the required voltage rise due to shunt capacitor bank is so, we want to increase or we want to rise the voltage by 1.6 percent. So, 4.6 percent is actual drop and we want to improve it to 3 percent, then total of improvement in voltage is 1.6 percent. To improve this voltage we would like to calculate the rating of the capacitor which will improve this voltage to by 1.6 percent.

The required rating of shunt capacitor is then we know that K rise factor is percent voltage rise divided by kVAr divided by kilometer. And in that case total kVAr we can easily calculate, it will be percent voltage rise divided by your K rise factor multiplied by kilometer. So, you kVAr of the capacitor can be easily calculated by this formula, which is percent voltage rise per of divided by your K rise factor multiplied by your kilometer. So, percent voltage rise is 1.6 percent K rise factor is 0.000265 which is we are calculated in last slide and kilometer length of the feeder is 2.4 kilometer. So, in that case your kVAr of the capacitor required is 2516 so, we need capacitor of this size so, that voltage limit will not get violated.

Let us see the summary of this lecture. So, we are started with chapter number 2 that is approximate methods of analysis of distribution system, where in this lecture number 6 we have started with K factors. And then we have seen two types of K factors, one is K drop factor and K rise factor and their applications. So, we have seen that K drop factor is nothing, but percent a voltage drop for 1 kVA load for 1 kilometer. Similarly, K rise factor we have seen that percent voltage rise for per V per kVAr capacitor loading per kilometer.

Thank you.