Power Electronics and Distributed Generation
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Module - 03
Lecture - 29
Distribution System Problems and Examples

Welcome to class 29 in topics in power electronics and distributed generation, today we will be discussing few problems these are home work problems for the students in the class and example problems for the students watching on the net. So, the first couple of problems are related to distribution systems and relaying and then the other two problems are related to economic decisions that you could make in making engineering choices for D G systems.

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1. An OLTC at a $66/11kV$ substation has 9 taps with a tapping voltage step of $0.02pu$ per tap. Tap-1 corresponds to $0.92pu$, Tap-5 corresponds to $1.00pu$, Tap-9 corresponds to $1.08pu$ output voltage on the feeder at the substation at nominal primary voltage. An overhead $11kV$ line has length of $6km$. The feeder line has an impedance R_L of $0.6\Omega/km$ and has X/R ratio of 1. The loading is uniform at $25A/km$ at a power factor of 0.9 lag. Clearly plot the different cases indicated in the problem below.

   (a) Design a circuit to implement the on load tap changer such that there is no voltage interruptions seen by the load and no over-current in the windings that are being switched. Describe the sequence of switching operations to obtain on load tap changing in steps of one and to keep the maximum currents during tap change to be less than the transformer rated current.

NPTEL

So, the first problem we are looking at a on load tap changer which at a distribution substation a 66 slash 11 K v and the substation transformer has 9 taps and each tap step is of 0.02 per unit, so tap 1 corresponds to 0.92 per unit tap 5 corresponds to 1 per unit.

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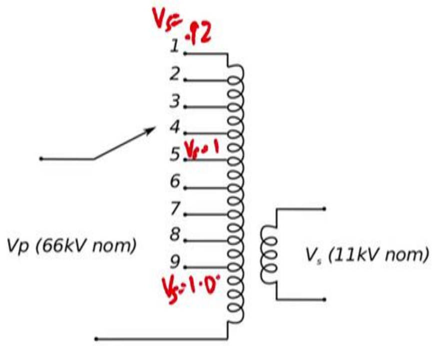
On-load Tap Changer



So, if you are looking at a single line diagram you are having taking the on load tap changer as a depending on where you are placing the taps, so here if you are at a tap 1 your secondary voltage would be 0.92 per unit. At tap 5 your secondary voltage would be equal to 1 per unit at tap 9 where the primary turns is say the small lowest then your secondary voltage would be the highest, so V s would be 1.08 per unit.

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So, this is when you are having nominal voltages at the input and output and you are having an 11 K v over headline of 6 kilometers going out from the substation. You are given the feeder line has an impedance resistance of 0.6 ohms per kilometer x by r ratio is equal to 1, the loading of the feeder is uniform 25 amperes per kilometer.

So, total 25 into 6, so 150 amps, total for this single 6 kilometer feeder and at a power factor of 0.9, so you want to make plots of voltage profile current profile etcetera. So, first will look at the circuit implementation of the tap changer and, so how the on load tap changing is being achieved, so if you want to change taps in structures as this.

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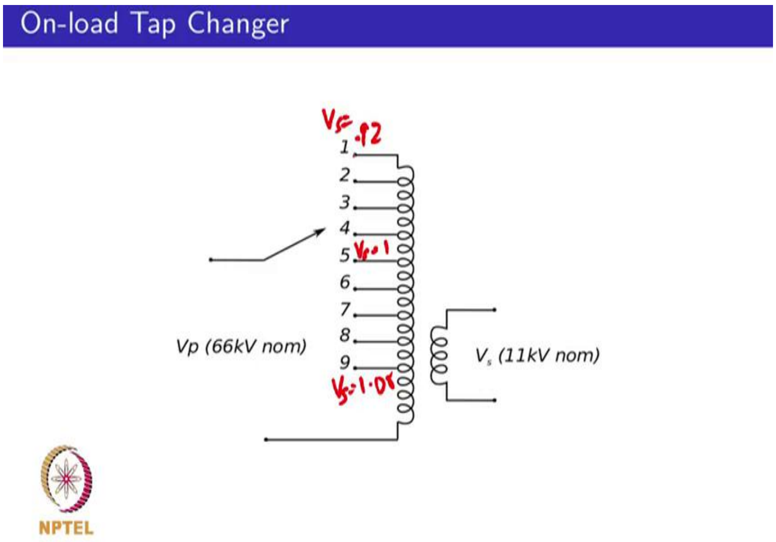

So, if you want to go from 1, say tap 1 to tap 2 if you do it without interruptions, if you simultaneously contact 1 and 2 then you are shorting a coil, so you can end up with large currents in shorted coil, so how is that achieved.

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NPTEL

So, what is the sequence of operations to actually limit the maximum current during tap change to be, say 1 per unit the rated current when you are doing the switching action.

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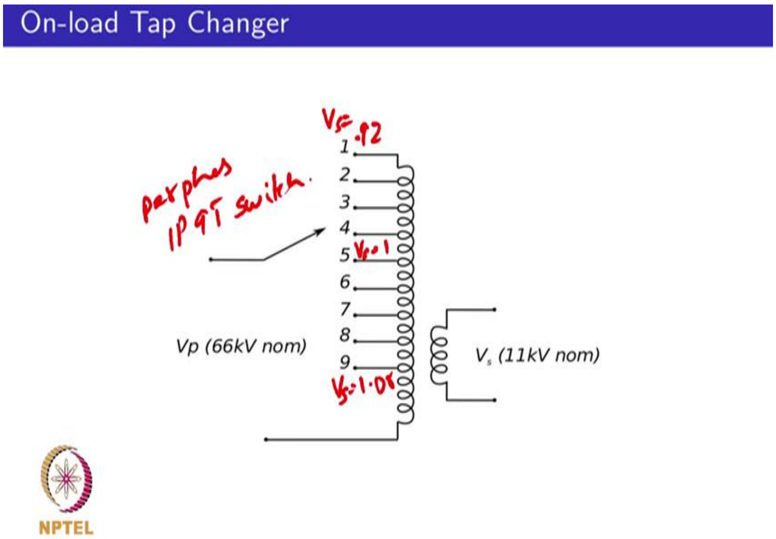

So, one possible configuration for, so if you look at the tap changer you can think of it as a 1 per phase bases it is a 1 pole 9 throw switch. So, if you on a 3 phase bases it is a 3 pole 27 throw switch, so it is a, is essentially a switching action between multiple throw points.

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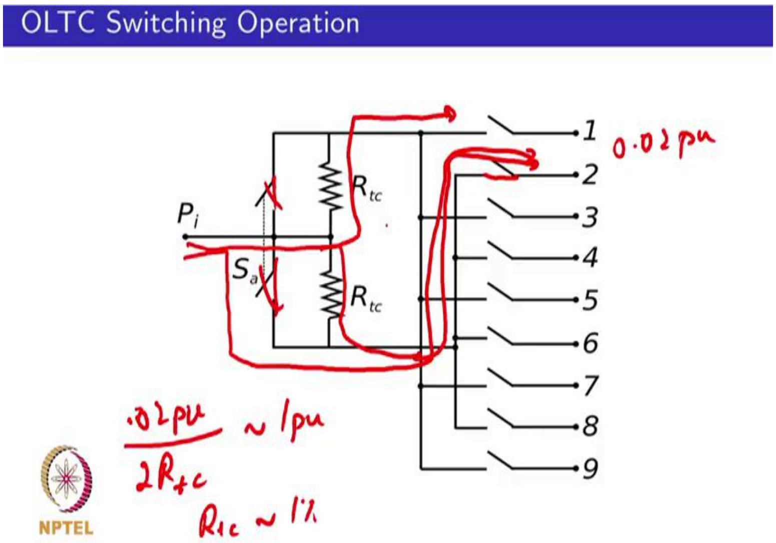

So, how could the switching action be achieved while limiting the short, the shorting current, so you could include resistors resistance of the tap changer to actually ensure that when you are actually having a shorted loop you limit the current. So, a sequence of actions for the tap changing could be say originally you might be connected to tap 1, so the switch might be closed and under normal conditions your switch S a would also be closed. So, this switch would be enclosed position, so your poleis connected to throw number 1 through the switch S a, and through switch 1.

So, this would be your starting configuration you want to eventually go to a configuration where switch 2 is actually connected to the throw corresponding to switch 2 is the one that is connected. So, the first step would be to open switch S a, so once you open S a, the power flow would then be through a the resistance R t c. So, you want to have a small value of resistance so that you do not have large drops in voltage and will see that a small value of resistances sufficient. So, once you have the S a open then at this point you could then close a your throw 2 and with throw 2 closed and with S a open.

Now, you have the resistance 2 R t c in the loop, so if you want to limit this particular current to be less than 1 percent we know that the voltage over here is 0.02 per unit. So, you want 0.02 per unit divided by twice R t c to be roughly 1, your 1 per unit current which means that your R t c is about 1 percent resistance. So, it also meets the criteria that when you open the switch you will not have a large drop across that particular resistor. So, this would be your second condition where you have close switch 2 then under this condition you could now open the throw 1 in which case the current flow will actually change from the top.

It will actually now flow through this particular path and then you could close switch S a back and because switch S a is closed, now your current diverts through the switch. So, it means that the losses in the resistor will be happening only during the transition time you might be operating a transformer, may be in many tens of minutes may be an hour. It is not like something some that switches very frequently you are trying to ensure that over the course of the day. So, when the voltage levels over a longer time frame changes you want to ensure that your secondary seize the nominal voltage.

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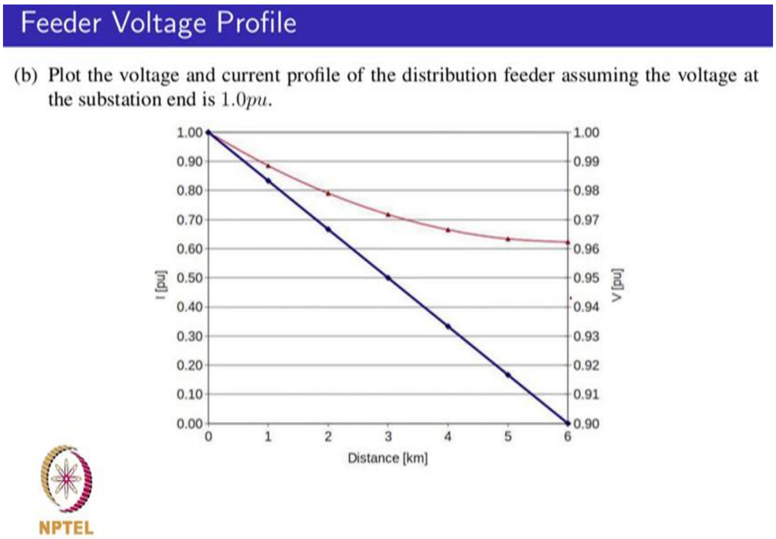

So, in the next problem you are asked to plot the voltage and current profile on the distribution feeder assuming the substation in voltage to be equal to 1 per unit. Now, this is based on the expressions that we derived in class and will also be discussing it in part c of the problem. So, we know that with uniform loading your current profile is going from 0 to 1 per unit and in a in a uniform manner with a constant slope because the loading is uniform. The nature of the voltage profile starting from 1 per, 1 per unit at the substation end it drops to about point slightly higher than 0.96 per unit at the, at the end and the expressions for this we will actually look at in part c of the problem.

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(c) At what distance from the substation should the voltage be regulated to nominal so that the voltage regulation range in the whole feeder is kept minimal?

So, the question is if we have a voltage profile that looks like this.

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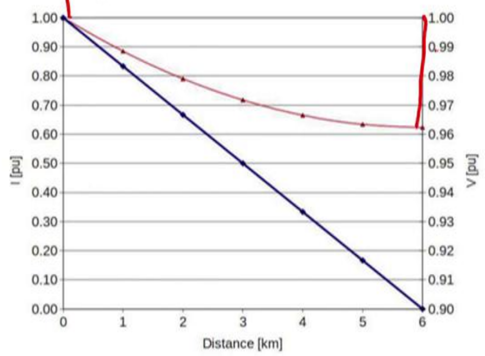
Feeder Voltage Profile

(b) Plot the voltage and current profile of the distribution feeder assuming the voltage at the substation end is $1.0pu$.



We do not want just the loads connected at the feeder end to c close to 1 per voltage, we want to the average user of this particular feeder to see voltage close to 1 per unit. So, it would be nice to actually ensure that the deviation at both ends of the feeder stay roughly equal, so that you are within the same tolerance range across the entire feeder.

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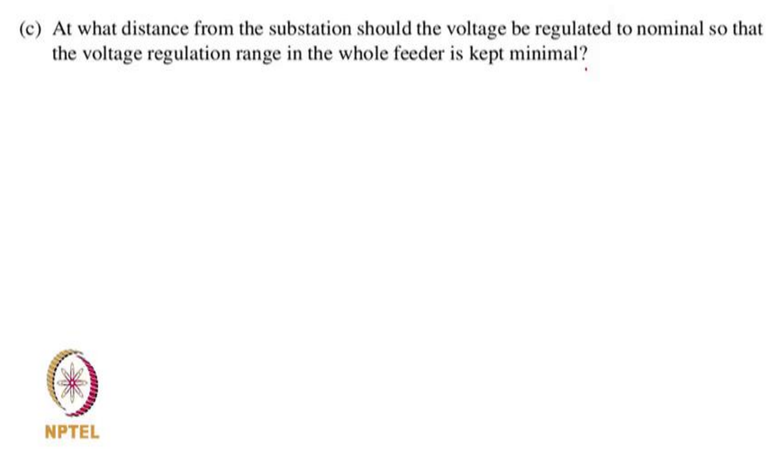

So, for that to happen what should be the distance from the substation that the voltage should be that that is regulated to the nominal value, so that the whole feeder voltage is kept minimum.

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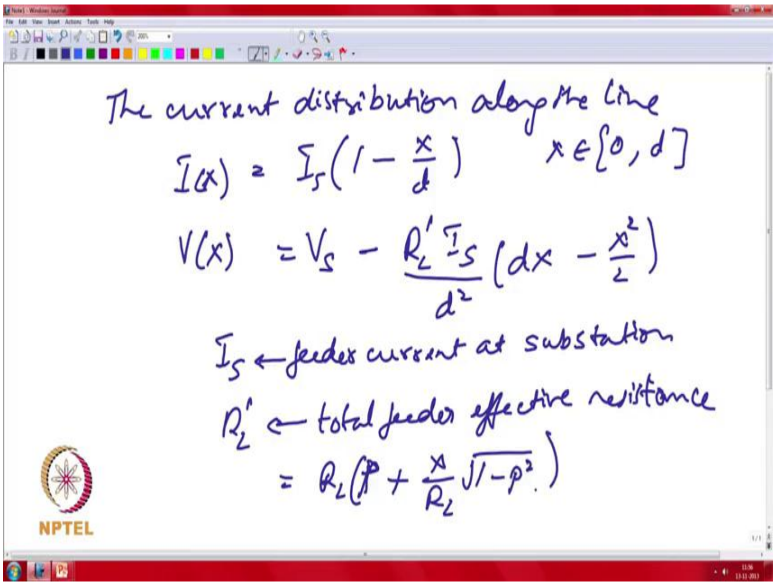

So, for that we the current distribution along the line is given by, so I at position x is I s into 1 minus x by d x belongs to 0, d and the voltage at x is the voltage at the substation minus r l prime I s. So, we had derived this in class and I s is the feeder current at the substation and your R L prime is the total feeder effective resistance. So, it is given by R

L which is the actual resistance into p with power factor plus the x by R ratio of the line into square root of 1 minus p square.

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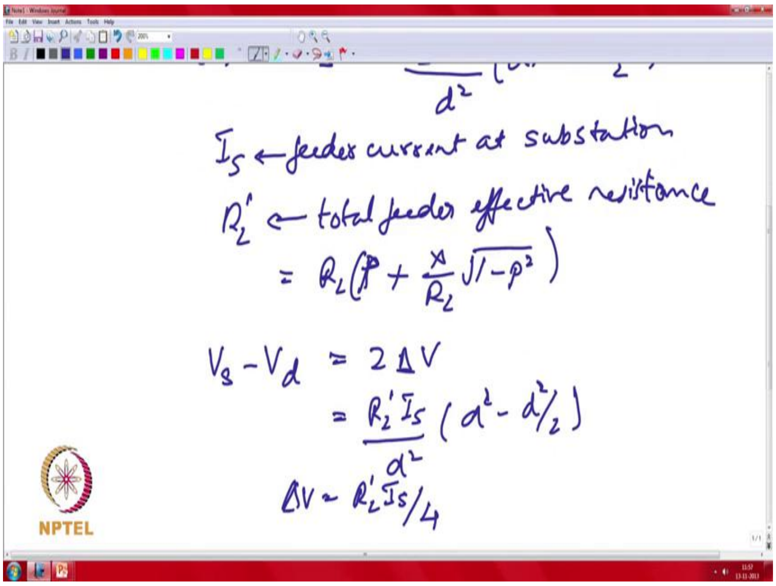

So, if we take the voltage at the end of the feeder to be V d and V s to be the voltage at the substation end and we want this to be equal to 2 delta V then this is given by R L prime I s by d square into d square minus d square by 2. So, delta v is R L prime I s by 4, so if we ensure in this particular, so if we ensure that this delta V range is equal to the particular value. Then your average user of the on the feeder will see voltage in the appropriate range, so the distance at which you get this particular value for delta V is R L prime I s, that is what we need to solve.

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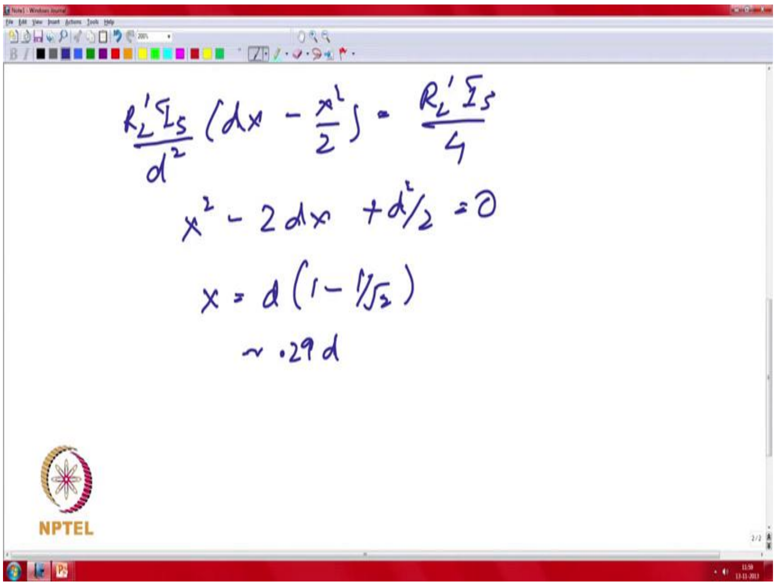

So, we want to ensure that the voltage drop at x d of x, x square by 2 is equal to this particular value which is R L prime I s by 4. So, this is a quadratic equation in x which can be solved to get the value of x, so you have x square minus 2 d x minus plus d square by 2 equal to 0 and a solution in the range is 0 to d is d into 1 minus 1 by root 2.

So, this is equal to 0.29 roughly at one-third, the distance from the substation if you are regulating to the nominal voltage then over the entire feeder you will be within the same tolerance range. So, again this is assuming that you are having uniform loading you also assuming that your power factor is the same across the loads on the feeders. But, this gives you a feel for what would be the nature of the requirement to maintain the voltage along the feeder.

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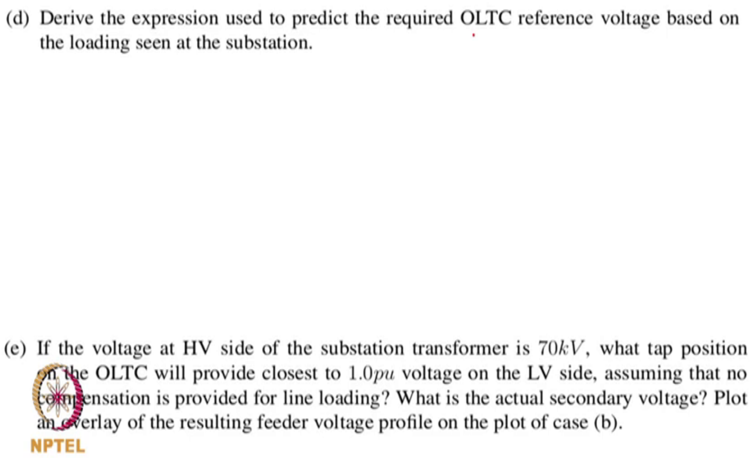
(d) Derive the expression used to predict the required OLTC reference voltage based on the loading seen at the substation.

(e) If the voltage at HV side of the substation transformer is $70kV$, what tap position on the OLTC will provide closest to $1.0pu$ voltage on the LV side, assuming that no compensation is provided for line loading? What is the actual secondary voltage? Plot an overlay of the resulting feeder voltage profile on the plot of case (b).

So, in the next problem we would like to see what could be an expression that could be used at the transformer to predict the reference voltage. So, that is required the substation end based on this loading that we have just derived to ensure that the voltage regulation across the feeder stays in the required range.

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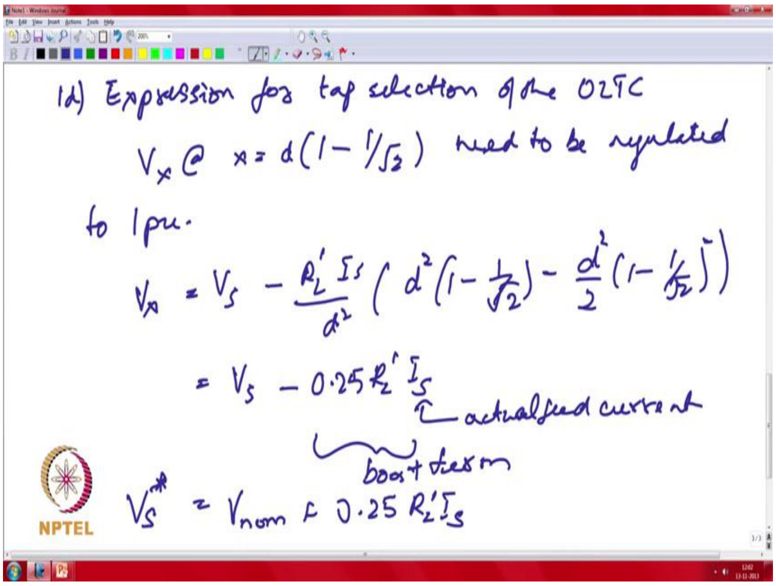

So, we want V at x to be at x is equal to d of 1 minus by root 2 need to be to 1 per unit and this is a open loop because you are not expressively taking measurements from that particular point and using it to control the tap selection. So, you have V at x equal to V s minus R L prime I s by d square into d square 1 minus 1 by root 2, so this simplifies to V s minus 0.25 R L prime I s. So, you look at the total current at the substation end, so this essentially your actual feeder current and this term over here is essentially a voltage boost.

So, if you look at the actual voltage it has to be commanded at the substation V s star it would be your nominal voltage, you want to keep this particular value V at x to be equal to the nominal. So, this is V nom plus 0.25 R L prime I s, so this is essentially a boost term you are providing and here we are assuming that the in actual substation there are multiple feeders.

So, we are also assuming that all the feeders have similar characteristics over the day, so it is not just that one particular feeder has load the other has no load. So, it is a similar type of consumption on depending on the time of the day etcetera and you want to actually provide a boost action across all the feeders that go out from this substation.

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(d) Derive the expression used to predict the required OLTC reference voltage based on the loading seen at the substation.

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So, in the next part of the problem we are looking at the voltage at the high voltage and if it is 70 K V what would be the tap position of the on load tap changer. But, that would provide closest to 1 per unit voltage on the Low voltage side assuming there is no compensation provided for line loading. So, without the boost action what would be the voltage just assuming the primary side voltage that has gone now high, so what is the actual secondary voltage in this particular case.

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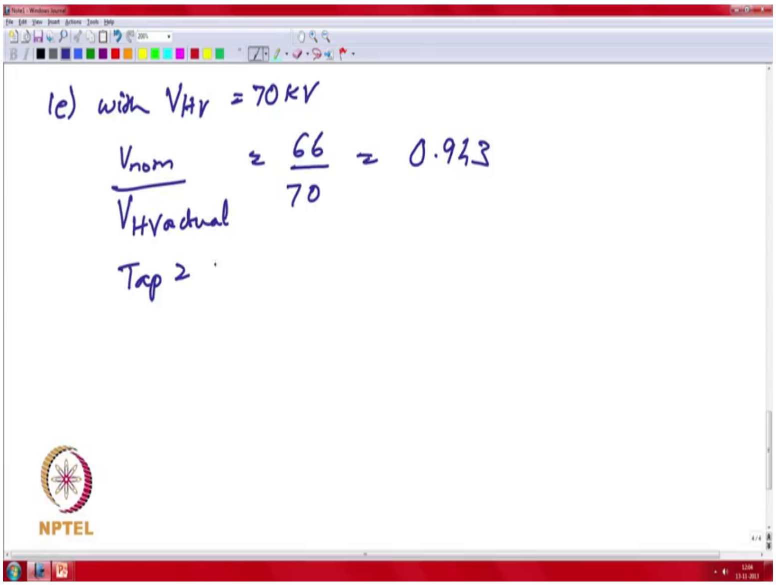

So, your V nom by your V at high voltage actual would be 66 divided by 70, so this corresponds to 0.943 per unit, so if your V is actual 66 K v, you would be at 1 per unit. So, because your actual voltage is now lower, so you your ratio turns out to be 0.94 if you look at what would be the closest tap that provides this particular voltage it would be the tap it would be the second tap.

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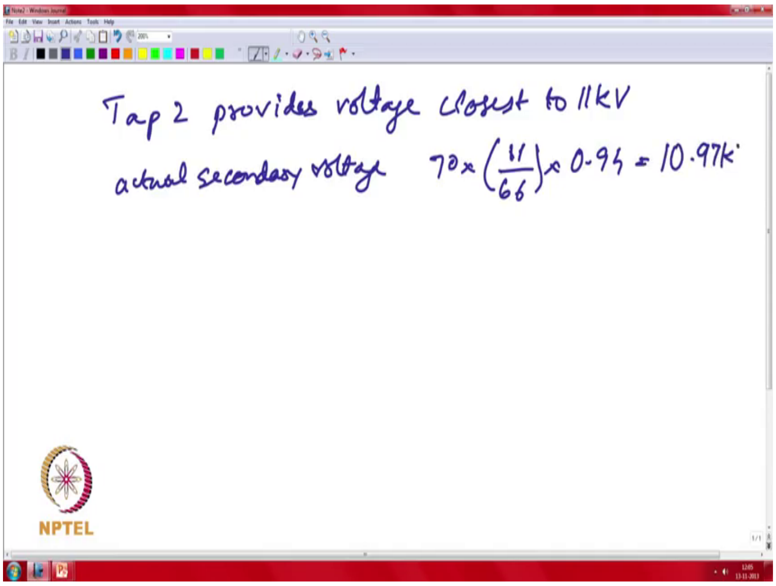

So, closest to 11 K v voltage it would be tap 2, so if you look at your actual secondary voltage, so you have 70 into 11 by 66 into 0.94 which is the tap that has been selected, so you have 10.97 K v and then if you look at the corresponding feeder voltage profile.

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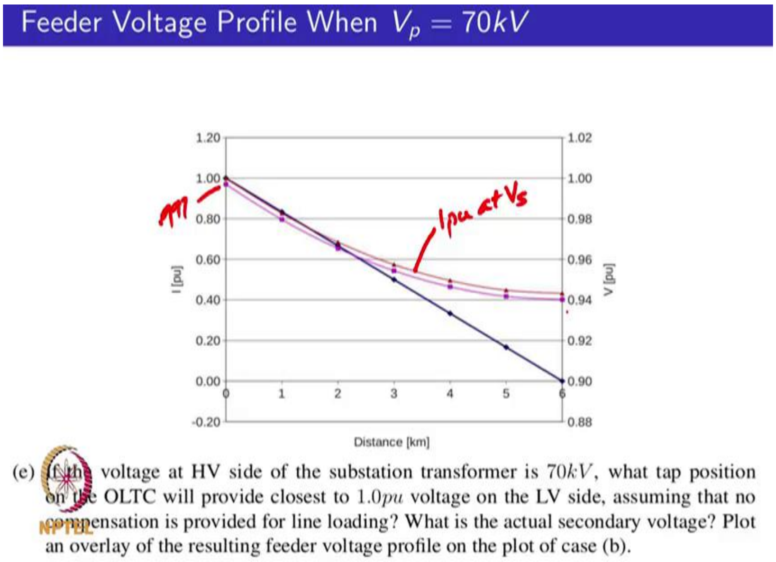

So, you would have, so the one start, the red one starting from 1 per unit is the one corresponding to the base case where you have one particular unit at the substation at V s. So, at d equal to 0, so you can see that in this particular case even though the secondary voltage has gone higher to 70 K v. But, the actual voltage at the substation end is actually starting at 0.997 and falls down in a similar trend because the impedance profile is the same along the feeder.

So, it is not necessary that you have a higher voltage on your primary you will see the same effect, on the secondary depending on the tap selection. You could have voltage which could beyond either side again this is because of the finite quantization effects you have only 9 taps, you do not have a smooth variation of the taps starting from say your minimum value to your maximum value.

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(f) What is the tap position on the OLTC that will provide closest to $1.0pu$ voltage at distance obtained from part (c) with line loading compensation and HV side at $70kV$. Overlay the resulting voltage profile on the plot of case (e).

So, in the next problem you are asked to actually look at what is the tap position that the transformer the O L T C will provide closest to 1 per unit at a distance, that is obtained in part c where we are looking at what position along the feeder you would like to regulate. So, here we are looking at the line loading compensation at a loading of 25 amps per kilometer and when the high voltage side is sitting at 70 K v.

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1(f) The line drop compensation needs

$$V_s^* = V_{nom} + \left(\frac{R_L' I_s}{4}\right)$$

$$= 11\,kV + (\quad)\sqrt{3}$$

$$= 11.31\,kV$$

$$\frac{V_s^*}{V_{nom}} = 1.028 \leftarrow \text{Shift tap by 1 step to boost voltage} \Rightarrow \text{Tap 3}$$

$$V_s \text{ actual} = 70 \times \left(\frac{11}{66}\right) \times 0.96 = 11.2\,kV$$

So, in this particular case if the, so one thing when we consider say if we take 11 K v as your primary plus your parameters of your substation current to be say 150 amps your resistance of R L prime based on the calculations we have just made. So, one thing to note this is on a phase bases, so where as your 11 K v is a line to line so you need to make sure that you consider things on a line to line bases including the appropriate change in voltage.

So, this turns out to be 11.31 K v, so if you look at your V s star by V nom you get 1.028, so again it is between 1.2 and 1.4 the closest being 1.2. It means that you need to boost of one tap because of the loading effect so your actual voltage, so previously you are sitting at tap 2. So, if you boost it by one tap you now go to tap 3, so if you look at the fee feeder voltage profile with ah with the line loading compensation you will see that.

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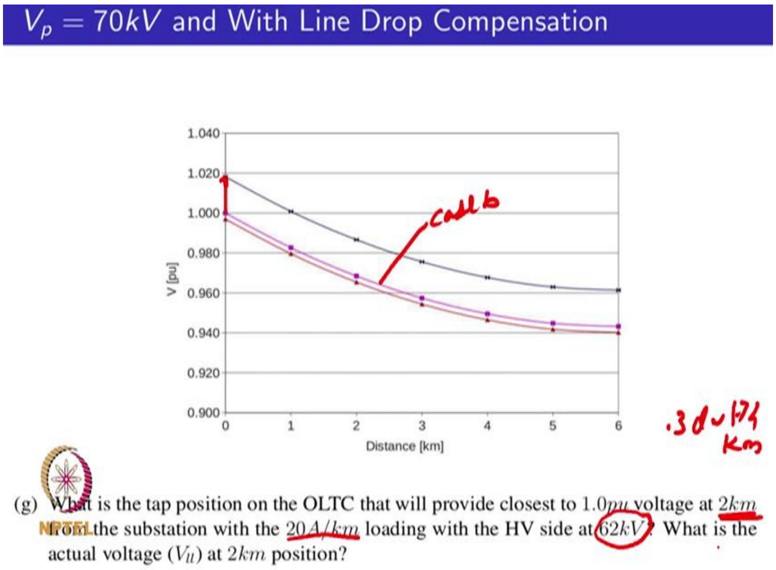

So, the original case b was this one, in the next case we were looking at the effect of just the voltage going to 70 K v. Here, you can see that you are getting a boost effect of due to the line loading compensation ideally you would like to boost a bit to, so that one-third, at one-third distance you would get close to 1 per unit. But, because use your actual selection was 0.28 if it was boosted by one more step the voltage at the substation and would have gone to high, so this would give you the processed to the desired profile.

So, in the next problem instead of boosting it at say 0.29, 0.3 d, so 0.3 d would correspond to about 1.74 kilometers, so instead of boosting the voltage at the 1.74 kilometers, if you say you want to boost it at 2 kilometers distance. So, that you want to have a slightly higher boost action then what would be the voltage, here for this particular problem you are considering a slightly lower loading of 20 amps per kilometer. But, we are considering a voltage on the high voltage side at of 62 K v, so we are looking at the this particular nature of the voltage profile.

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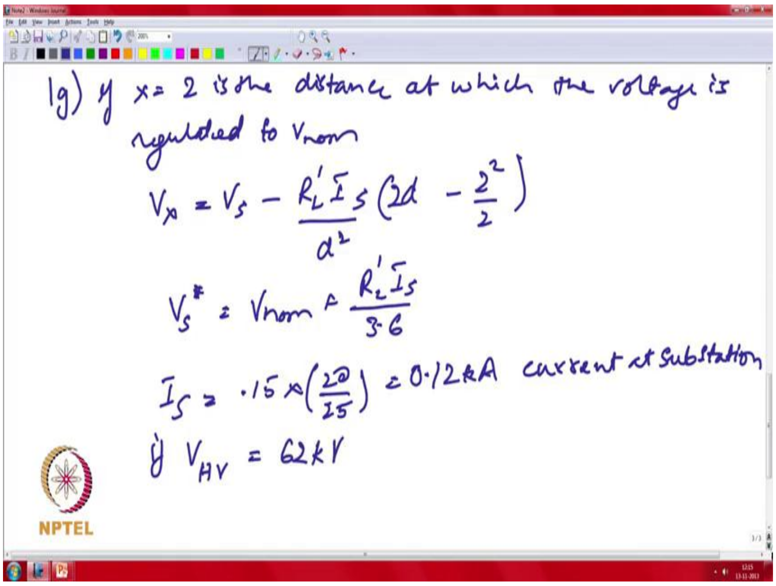

So, if you get V of x due to V s minus R L prime I s by d square into 2 d minus 2 square by 2, so essentially you get V s star is equal to V nom plus R L prime I s by 3.6. So, essentially you get a slightly different boost term and if you look at the situation where in this particular case I s is it would have been 100 and say 0.15 kilo amps at 25 amps per kilometer loading at 20 amps per kilometer, loading you have 0.15 into 20 by 25 equal to 0.12. So, this is a current, so if your high voltage primary side voltage is 62 K v your desired tap point.

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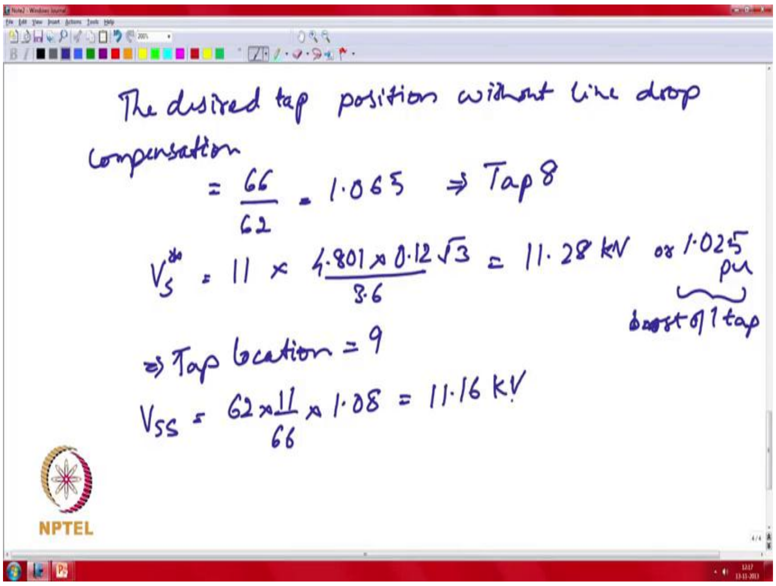

So, if you look at what is the closest to 1.065, so after 1.06 you have 1.08, so which is tap 9, so this would correspond to tap 8 would be the closest tap and your V s star. In this particular case would be 11 K v plus 4.801 which is in which is your R L prime into 0.12 root 3 by 3.6 this would correspond. So, essentially again this would correspond to boost by 1 tap, so your actual tap location would be tap 8 plus 1 tap boost or your line drop. So, your tap your actual tap location is 9 and your secondary side voltage would be 62 into 11 by 66 into 1.08 which would be 11.16 K v.

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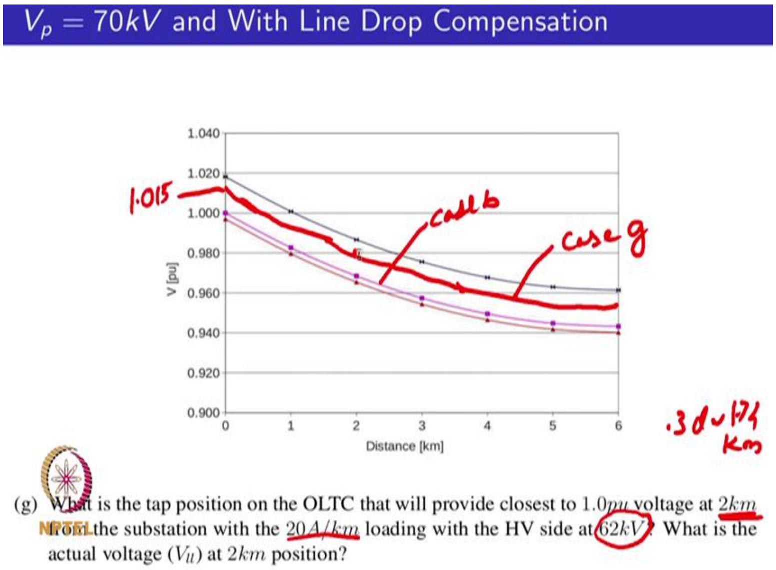

So, if you look at where it would lie it would essentially lye starting at somewhere around here this would because g, so starting at around 1.015. So, at distance 2 it is again point around 0.98 per unit, so again because of the finite number finite number of taps you have these quantization effects. Now, which means that you cannot actually exact number that you are targeting, but it would be the one that is close closest.

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(h) The line capacity is increased by connecting two conductor in parallel in the feeder. With the two parallel conductors and other conditions as in question (b), what is the new voltage (V_{llrms}) at the end of the line? Note: The case considered is parallel conductors and not the case of two parallel overhead three phase lines.

So, in the next problem we are looking at the options for increasing the capacity of the line and we are considering the case where two conductors are placed in parallel on the on the particular feeder. So, in this particular situation what is the new voltage at the end of the line and the case that is being considered is parallel conductors and not the case of parallel lines. So, we will look at what could be the possible situations that you could have when you are say paralleling conductors.

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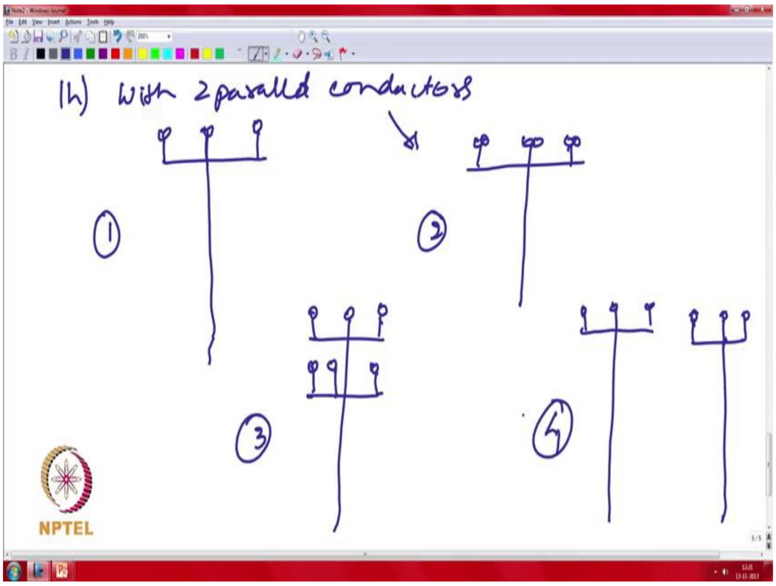

So, if you look at the original line, so your, so your original line might have say a pole with say 3 conductors on top, so this might be your original configuration. So, we are looking at say configuration 2 where you have a pole and you have now parallel conductors on each insulator.

Now, you could also, this would be the parallel conductor case you could also have other configurations say you could have a configuration such as this where you put 2 cross arms and then you have say conductors on now both cross arms. So, we could have 2 poles, so you could look at what is the effect of these different configurations, so here you could you could think about this as a parallel feeder line parallel circuit, so say this is op case 3, case 4 if you look.

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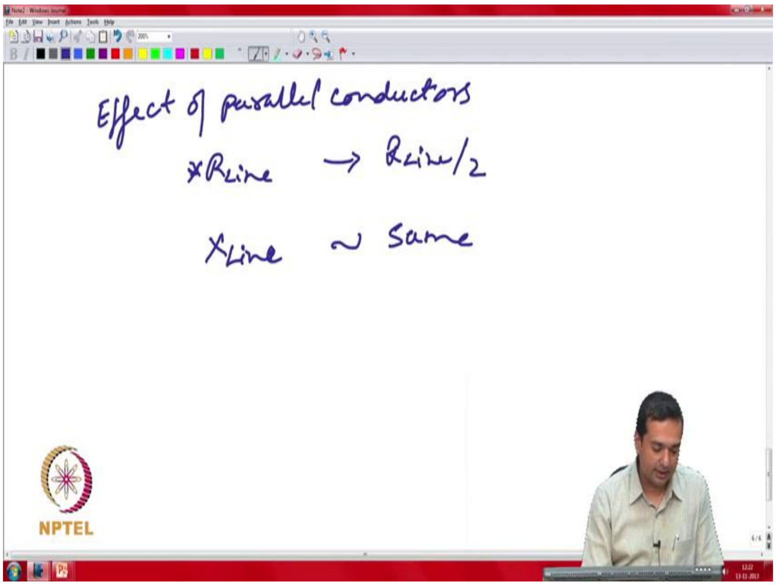

So, effect of you will see that your r line is half because you now have twice the effective cross sectional area, so it becomes r line by 2. But, your x lines stays roughly the same, so your x value does not change because your loop areas are not significantly different for the current conductors the distances between your conductors are roughly the same. Whereas, if you now look at the case where you are having a say parallel conductors you now have effectively 2 parallel impedances, essentially you will be changing your x line also.

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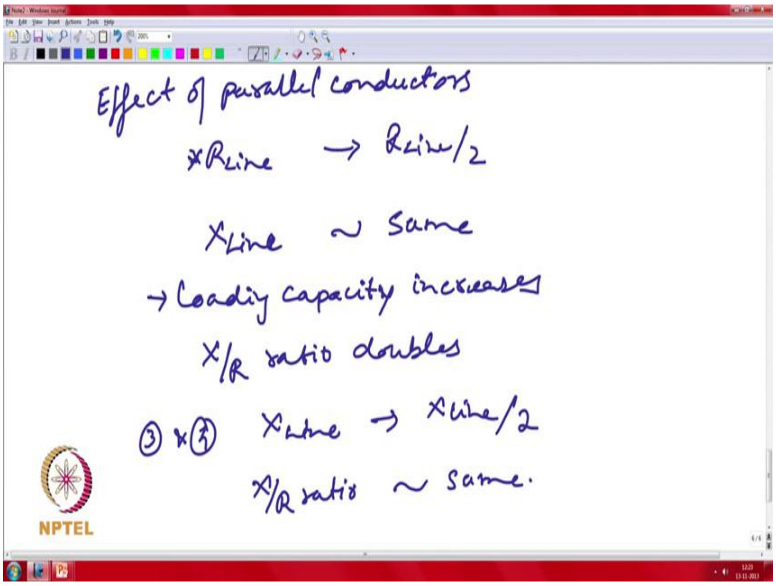

So, here your loading capacity increases your x by R ratio changes, so your x by R, whereas in option 3 and 4 your x line would shift to approximately x line by 2. So, that means that your x by R ratio would stay roughly the same, so with this you could then calculate what is your effective, say resistance of the new line.

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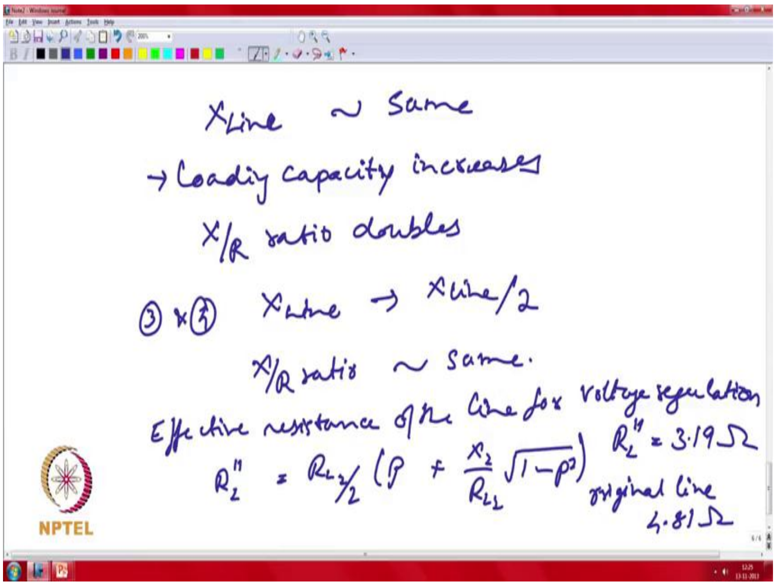

So, your voltage regulation calculation your R L double prime is R L 2 by 2 because your resistances is half, but your power factor is P x 2 by R L 2. So, you look at your R L double prime this is 3.19 ohms, whereas if your original line this was 4.81 ohms, so because you now have just parallel the conductors it does not half. But, it falls by a by some percentage but does not exactly half. So if you look at your voltage at the end of the feeder assuming 11 K v at the substation your V of d.

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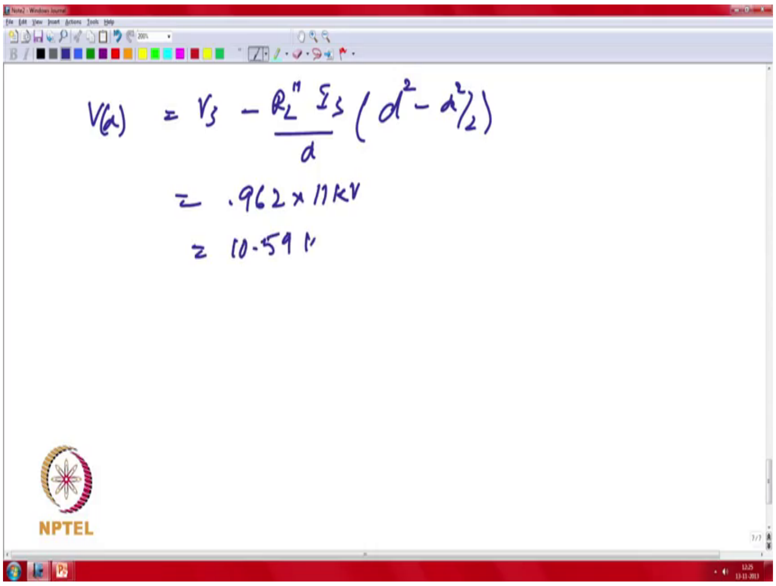

So, this turns out to be 0.962 times your 11 K v, so this is 10.59 K v.

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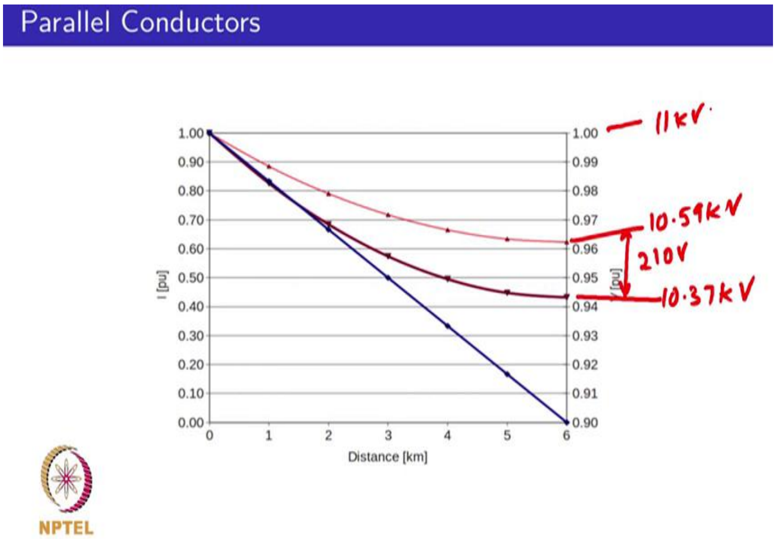

So, if you look at the voltage profile you can see that the original voltage went down to say 0.94 that was around 10.37 K v, now with the parallel conductors you have 10.59 K v. So, your voltage drop reduction is about 210 volts if this corresponds to 11 K v, so there is a reduction in voltage drop, but it is not as much as just taking the entire R L prime and taking half of that.

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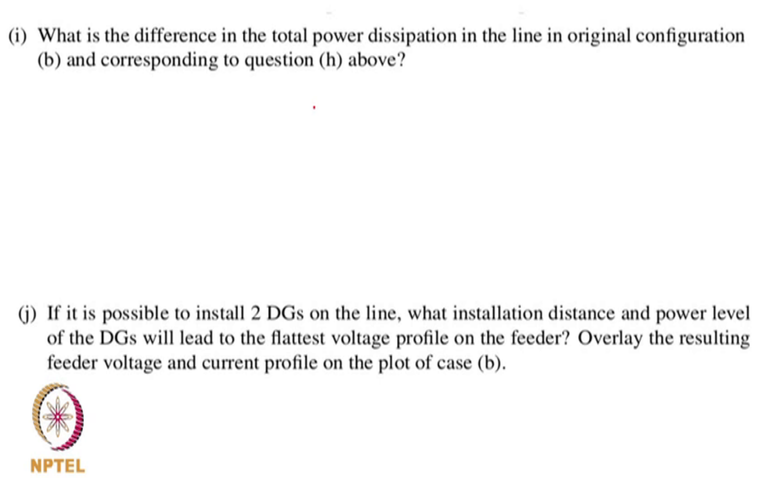

So, you could then ask what is difference in power dissipation in the line what is the power dissipation in that happens in the line. And what was it in the original configuration and what is it when you have the parallel conductor as a in the case above.

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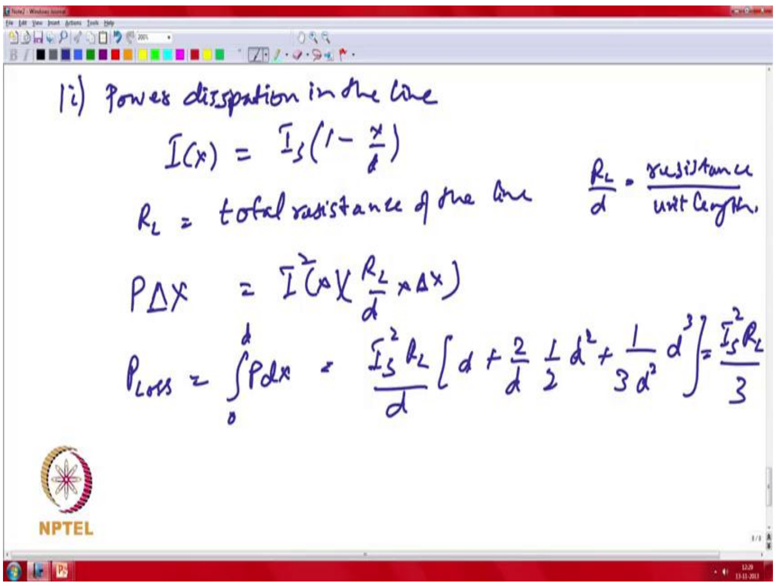

So, you can write an expression for the power dissipation in the line, so we know the expression for the current which is I s into 1 minus x by d and R L is the total resistance of the lines, so your resistance per unit length is given by R L by d. So, we can write an expression for what is the power dissipated along a incremental length delta x along that particular feeder is given by I of x square into R L by d into delta x.

So, if you integrate this along the line your power loss in the line would be and you can write the expression for that I s. So, you get I s square the d is cancel out R L by 3, so this is the power loss per phase of the feeder line, so you multiply by 3 to get the total loss on a 3 phase bases.

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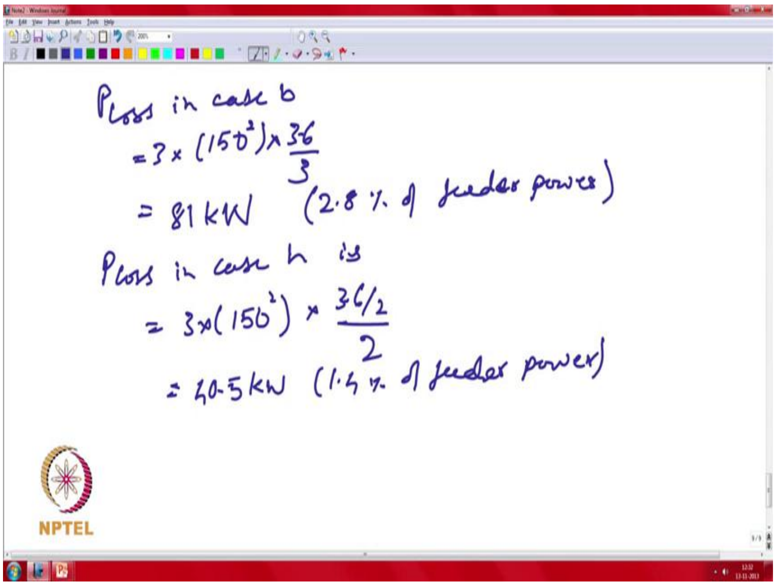

So, power loss in case b is 3 into 150, so this turns out to be equal to 81 Kilo watts, so 81 Kilo watts happen to be around 2.8 percent of feeder power. So, you can see that there is a quite a bit of loss along the feeder and when you have the parallel conductors its half of this particular number. So, you get 40.5 Kilo watts or 1.4 percent of feeder power and often the reason for putting parallel conductors are not from the power loss reduction perspective, it might be to increase the capacity of the line. So, the number that would be used when you have parallel conductors would be at not the same level of loading there will be increase loading.

So, because you now your purpose for adding the parallel conductor is to actually serve more loads often and the limitations of how much power dissipation is often related. So, what is the temperature rise that the conductors could see which would also limit how much loading can happen on a per kilometer bases. So, in the next problem you are asked if you have now 2 D Gs that are installed on the feeder where would you locate it.

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(i) What is the difference in the total power dissipation in the line in original configuration (b) and corresponding to question (h) above?

(j) If it is possible to install 2 DGs on the line, what installation distance and power level of the DGs will lead to the flattest voltage profile on the feeder? Overlay the resulting feeder voltage and current profile on the plot of case (b).

So, there are if it is possible to install 2 D G on the line at what distance in power level would the D Gs lead to flats voltage profile on the feeder and look at the resulting voltage profile.

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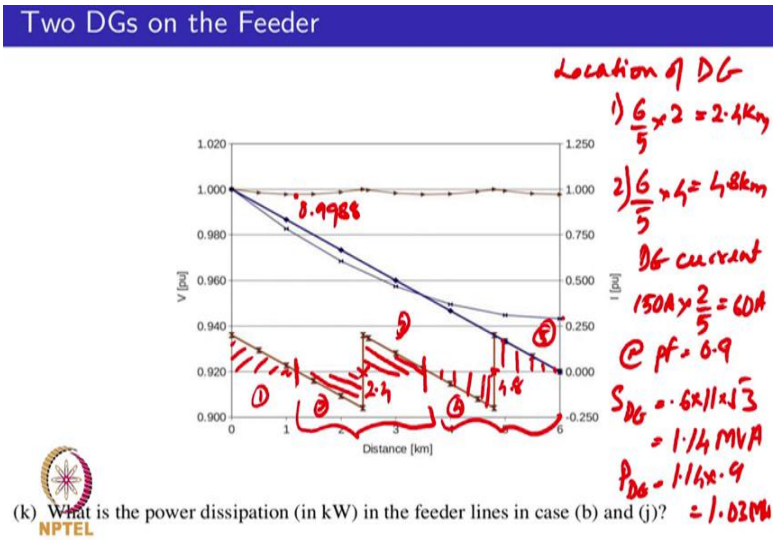

So, if you look at the case of adding the fluid the 2 D Gs you can see that most of the voltage drop occurs because of the higher it drops that are occurring on the feeder. So, an objective of adding a D G would be to actually reduce the drop the R is the property of the conductor what you can alter is the your current profile and by adding a D G at a distance of at 2.4 kilometers which is two-fifth of the distance. Now, at 4.8 kilometers you can actually bring down the current level amplitudes of the current to be the smallest along the feeder.

So, if you look at the power flow in this particular case essentially your substation power is actually flowing into a short distance. Over here, say section 1, section 2 and say section 3 the power is flowing from say the D G in section 4 and 5 is flowing from say D G number D G number 2. So, if you look at then what would be the power rating for your two D Gs your D G, each D G would need to actually supply the power corresponding to this particular section of the feeder and the power level would be.

So, there are 5 identical sections and the total length is 6, so 6 by 5 and the location of first D G at the between your second and third section. So, you have 2.4 kilometers the second is 6 by 5 and the location is between your forth and the fifth. So, that is why you get 4.8 kilometers and your D G current rating would be 150 amps which would be the total overall, but you are supplying it, now to 2 sections into 2 by 5. So, it is 60 amperes at power factor of 0.9, 0.9 lead because the loads are at 0.9 lag, so if you look at your m v a level of your D G this is 0.6 into 11 it is about 1.14 m v a and your power level is about 1 Mega watt.

So, you need about 21 Mega watt D Gs located appropriately to get the flattest possible voltage profile if you look at the voltage drop. Now, you can consider a short feeder of the length of say the triangle in section 1 and you can calculate what is the maximum voltage drop the lowest point, that it goes to is 0.9988 volts. So, there is a hardly any voltage drop you can see that in this particular case it was going to almost 0.94, so it is a the voltage drop.

So, it has become much flatter compared to the original situation the last part of the problem is what is the power dissipation in this compared to the previous case b then we could also consider the parallel conductors, the case when you have D G. So, you could essentially the procedure adopted could be you could calculate what is the power loss in one small triangular section and we know that there are 5 such sections to actually calculate the power loss.

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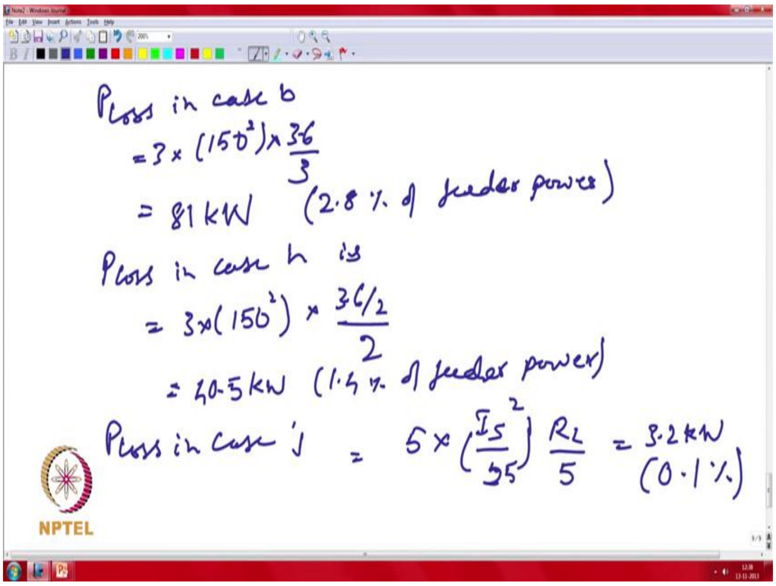

So, if you look at it on a percentage bases this is about 0.1 percent, so we can see that compared to the 2.8 percent in the original case the power dissipation has reduced almost by a very large factor and the power loss is reduced significantly. But, it is not always possible for us to sight D G is that ideal locations and your and supply power at the decide generating levels.

So, the D G can provide some level of service, but to increase the capacity of the line you need to put in parallel conductors. So, having both options of strengthening your system and adding distributed generation can actually give you or overall benefits. So, in the second problem is on switching that will discuss is on the switching.

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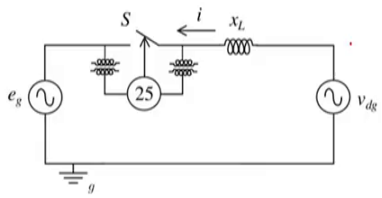
3. A switch, S, is used to interconnect a $100kW$ DG to the three phase grid, as shown in the figure below. The nominal voltage and frequency of the DG and the grid is $415V$, $50Hz$. The effective interconnection impedance is $j0.2pu$. The switch, S, opens when there is any fault on the grid. A synchronization check relay (**25**) is used to close S if the voltage, frequency and phase angle of the two sources are within a acceptable range so that the immediate peak surge current during the closing transient is less than $200A$.



(a) A fault on the grid causes the grid voltage to collapse to zero. What is the maximum possible value of peak fault current that can flow from the DG?

So, switching of a D G and the grid essentially you have a switch which interconnects a D G and the grid and you want to see what would be the transient currents under two conditions. One say when you are operating the D G in parallel when the switch is closed and say you have for some reason there is a fault and the voltage on the grid becomes a dead short.

So, you will have a transient current flowing out you want to actually look at what is that value then the second situation that you want to see is in response to the fault the switch has opened. Now, you have voltages of the grid and the D G which are closed by, but not exactly identical, so when you close the switch what would be the transient currents there are flowing between your grid and the D G, so for the first problem.

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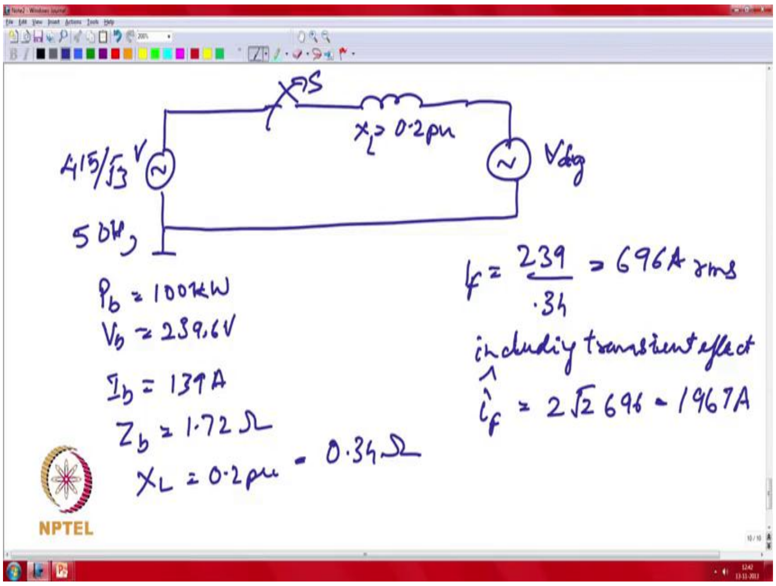

So, you are looking at a model, so D G is 100 Kilo watts your grid voltage is 415, so on a per phase base is 415 by root 350 hertz the switch was closed. So, you are opening at your X L is 0.2 unity our power is 100 Kilo watts power base v, base is 415 by root 3, 239.6 volts I base is 1.139 amps z base is 1.72 ohms. So, your x will of 0.2 per unit is 0.34 ohms, so if your I fault is 239 volts by 0.34, so it is 696 amps r m s, so if you are including taking the peak of the sinusoid you gets a factor of square root of 2 including transient effects.

So, due to large x by r ratios your peak fault current can be about twice square root of 2 times 696, so you are talking about 2 Kilo amps can actually flow out. So, when you have a dead short on the grid and your switch s takes a finite amount of time to open. So, before it opens you might end up with a fairly substantial peak current, so the second problem is about is about what would be the voltage.

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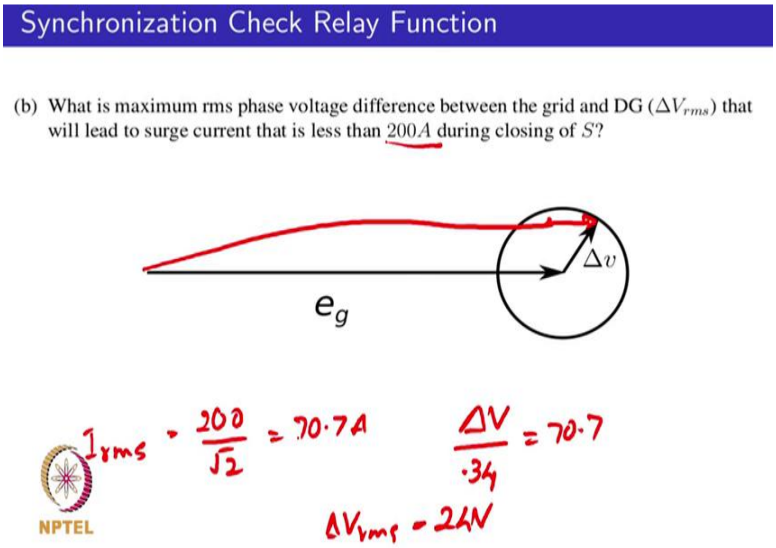

So, what would be the maximum voltage error between your grid and the D G that can be allowed the voltage error amplitude. So, that you your surge current is kept below 200 amps here will ignore the D G transient switching effect, so if you, but the 200 amps is the peak value that you want to cape your current below. So, you could calculate what your I r m s is 200 by root 2 is 70.7 amps and if you look at the circuit the error between your grid voltage and your D G voltage is the voltage that is being applied across the inductor.

So, you want to ensure that that voltage that is being applied has a magnitude such that the resulting current r m s current stays below these 70.7 amps. So, you have your delta V by 0.34 which is your impedance is 70.7, so your delta V r m s is 24 volts, so as long as your D G voltage lies anywhere in this particular circle you would be because your amplitude error will not lead to a current greater than 70.7 amps.

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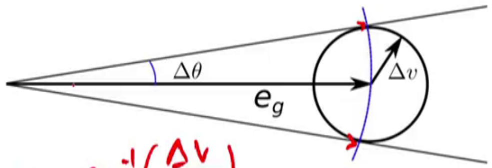
Synchronization Check Relay Function

(c) What is the maximum phase angle difference in degrees between the grid and DG ($\Delta\theta$) will lead to surge current that is less than $200A$ during closing of S?



$$\Delta\theta = \sin^{-1}\left(\frac{\Delta v}{e_g}\right)$$
$$= 5.8^\circ \ (0.102 \text{ rad})$$

NPTEL

So, in the next problem you are asked, what is the maximum phase angle difference between your grid and D G voltage such that this condition is satisfied. so, you can see that the maximum voltage error could occur when the voltage is such that it is just touching the circumference of the circle. So, this particular tangent is just touching the circumference of the circle at this point this particular tangent is touching at this particular point. So, you could then make use of that to calculate what would be the maximum angle error, so you have delta theta is sine inverse.

So, sine inverse delta V g delta V by your e g, so this turns out to be 5.8 degrees or 0.102 radiance, so it gives you estimate of how far you can actually let your angle b. So, that your surge current is kept below your desired 200 amps then in the next part of the problem you are told that instead of using 5.8 degrees you are actual relay is set to a close within a 2 degree angle.

So, this particular angle is held at 2 degrees and you are asked what is the maximum frequency difference between your grid voltage. So, your D G voltage such that you do not exceed 200 amps, so essentially your grid voltage and your D G voltage there might be 2 vectors.

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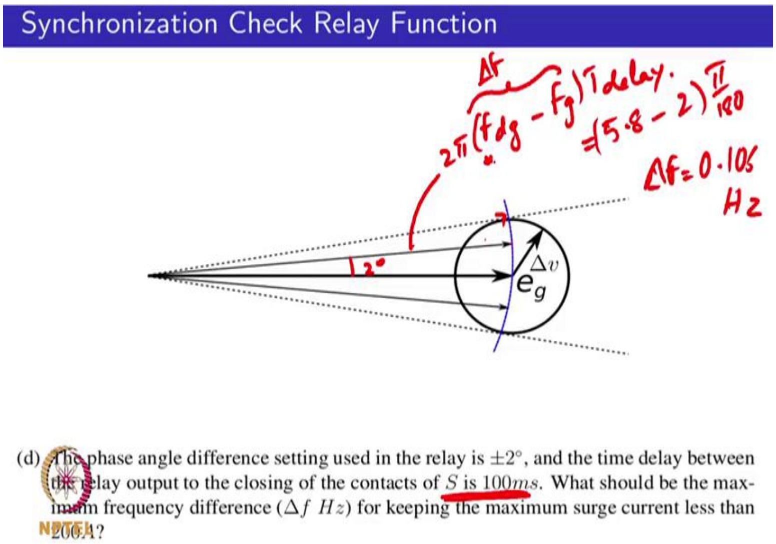

So, they are moving a part at frequency given by 2 P if D G minus f g into your delay time of operating your switch because takes a finite time for a switch to close. Here, you are told that your switch takes 100 milliseconds from your logic command to actual closing and you want to relate that to what is your maximum frequency error. So, you can then write an expression you can relate this particular angle to be equal to 5.8 minus 2 into pi by 180, so you get essentially this which is your delta f.

So, you get delta f to be equal to 0.106 hertz, so if your grid voltage is at 50 hertz you want to ensure that your D G voltage is 49.9 hertz to 50.01 hertz, 50.1 hertz. So, in that particular range to ensure that the surge current during closing will not exceed 200 amps under the condition that you are closing. Now, at an angle of 2 degrees rather than 5 degrees, if you are closing at this particular point because of the delay you might have gone out to something much further out.

So, you need to actually ensure that when you are closing a switch your amplitudes are matched your phases matched and your frequencies matched appropriately. In the next class, we will discuss couple of problems related to economics of operation of the D G which can help with your engineering design.

Thank you.