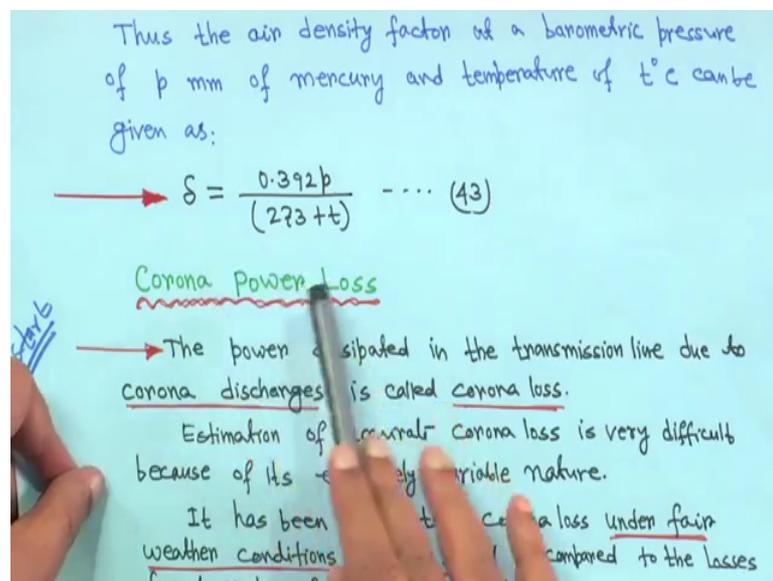**Power System Engineering**
Prof. Debapriya Das
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 22
Corona (Contd.)

So in the just we have seen that delta is equal to 0.392 p upon 273 plus t this is equation 43 say.

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Now, we will come to the corona power loss. So, whatever your visual critical voltage; disruptive critical voltage all we have seen. Now, we will come to the corona power loss.

So, basically the power dissipated in the transmission line due to your corona discharges is called corona loss. So, estimation of accurate corona loss is very difficult, it will almost impossible because of it is extremely well in nature; it depends on your so many factors associated with it, so all these things have been explained.

So, what happened? So, basically if you see under fair weather condition. So, corona will be very small, but under foul weather condition corona will be very high, as high as 10 times than the corona loss of your fair weather condition. So, that is why there is no you know you cannot give any formula for exact formula for corona loss, but some empirical

formula is available, I mean through the experimental test people have found some approximate formula.

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For example, F.W. peek, actually he gave this corona loss under fair weather condition and it is given this formula is it is under fair weather condition. It is something like 244 upon delta into a plus 25 into V n minus V 0 whole square into root over r by D into 10 to the power minus 5 kilowatt per kilometre per phase.

So, that means, this corona loss it is under fair weather conditions; that means, corona loss if you look into that is inversely proportional to the delta that is your density factor, directly proportional to the frequency, directly proportional to this V n minus V 0 square and also directly proportional to your root over r by D.

So, in this example for this formula P is the corona loss, Pc actually is the corona here, I have written Pc, so here it is P c. Pc is the corona loss, f is your supply frequency, delta is your density factor and V n is r m s, r m s a phase line to neutral voltage in KV and V 0 is r m s value of disruptive critical voltage per phase in KV, this is V 0, r is the radius of the your conductor and D is the spacing or equivalent spacing between conductors, if it is a single phase then it will be D, if it is 3 phase then you have to find out deq, that is your you know that the dab, dbc, dca to the power 1 3rd into 10 to the power minus 5 kilowatt per kilometre per phase.

So, this is actually your, what you call that corona loss formula under fair weather condition.

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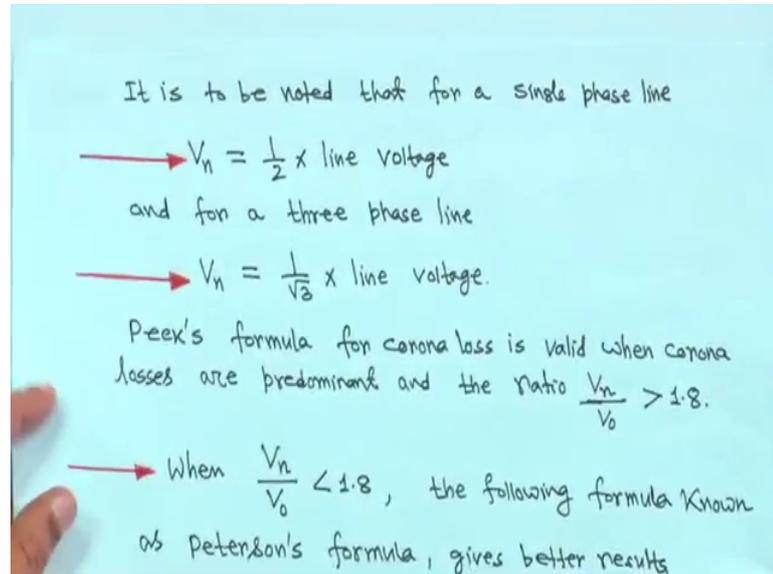
So, therefore it is to be noted that for a single phase line V n should be half into line voltage and for a 3 phase line this we have given earlier also it is 1 upon root 3 in to line voltage.

Now, peeks formula for corona loss is valid, when corona losses are predominant and the ratio V n by V 0 greater than 1.8, if this ratio is greater than 1.8 then peeks formula corona loss is quite valid, but when V n less than V n by V 0 less than 1.8 this ratio, the following formula known as Peterson's formula gives better result. So, there is another formula for corona loss that is called Peterson's formula if V n by V 0, your less than 1.8.

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$$P_c = 2.1f \left[\frac{V_n}{\log_{10}\left(\frac{D}{r}\right)} \right] \times 10^{-5} \times F \quad \text{kW/phase/km.} \quad \cdots (45)$$

Where

P_c = corona loss

f = supply frequency

V_n = rms phase voltage (line-to-neutral) in KV.

r = radius of conductor (m)

D = spacing (or equivalent spacing) between conductors (m)

The Factor F is called the corona loss function. It varies with the ratio $\frac{V_n}{V_0}$ and is given below in tabular form:

So, in this case that corona loss Pc is equal 2.1 into f in bracket V n upon log base 10, D upon r bracket close this is whole square into 10 to the power minus 5 into capital F, this is capital F kilowatt per phase per kilometre, what is capital F? I will be coming. So, P c is the corona log, f is your supply frequency, your V n is the, your r m s voltage line to neutral in KV, r is equal to radius of the conductor and D spacing or equivalence spacing between conductors. So, F this F is the factor actually F is called the corona loss function, I mean you have for different ratio V n by V 0 you can find out what is F? It varies with the ratio V n by V 0 and is given below in tabular form I will show you.

So, F actually is a variable, it depends on the V n by V 0 ratio that although in this function V 0 is not coming in this in this equation, but F is a function of V n by V 0, that means, this Pc actually is a function of V 0 also.

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$\dfrac{V_n}{V_0}$	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2
F	0.012	0.018	0.05	0.08	0.30	1.0	3.5	6.0	8.0

Factors Affecting Corona Loss

(A) Effect of system voltage

Electric field intensity in the space around the conductors depends on the potential difference between the conductors. If potential difference is high, electric field intensity is also very high and hence corona loss is also high. As seen from eqns. (44) and (45), when V_n is large as compared to displacive V_0, corona loss increases at a very fast rate with increase in voltage.

So, in this case that your V n by V 0 this side and this is your F. So, when it is 0.6 it is 0.012, 0.8, 0.018, when it is 1 it is 0.018, when it is 1.2 it is 0.08, when 1.4 it is point 3 increasing, I mean in a very a rapid when a V n by V 0 is a increasing, then 1.6 it is 1, when it is 1.8 it is 3.5 and it is 2 it is 6 almost 3 time and it is 2.2 it is 8.0, that means, when V n by V 0 ratio is increasing, this F is also increasing in a very it is faster rate.

So this, I mean if you solve a numerical and if Peterson's formula is given, then this table will be supplied such that you can you have the delta from this table.

Next one is, that is your factors affecting the corona. So, first one is the effect of system voltage in a transmission line for example, you take any 2 phase conductor and if you see the voltage applied across them is more, then naturally that potential your this thing electric field intensity also will be more, that means, any 2 conductor you take if potential difference is high, then electric field intensity is also very high.

Therefore, the hence the corona loss also will be very high, as seen from equation 44 and 45, when V n is large as compared to I mean 44, 45 just I showed you, this is 45 this Peterson's formula is 45 and your peeks formula is 44, this one is 44 that is your F.W. peeks formula for corona loss.

So, when V n is large as compared to V 0 corona loss increases at a very faster rate with increase in voltage because those are directly related to the your V n and your V 0 both, so this is the effect of system voltage.
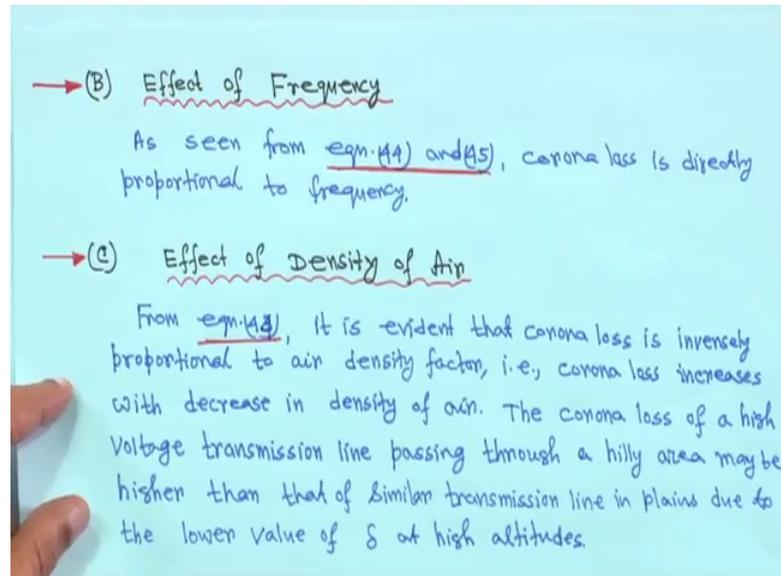
Next is effect of frequency, now again in equation 44 and 45 we have seen, the corona loss actually is directly proportional to the frequency, that means, this here also f plus 25 that will be f plus 25 is constant. So, it is directly proportional to this and similarly your this Peterson's formula here also directly proportional to f. So, that it I mean it depends on the frequency.

So, we have seen from that which has directly proportional to the frequency, but in a power network 50 hertz or 60 hertz there is not much change from the nominal value, nominal is 50 hertz that means, the slight increase or slight decrease depending on the power system condition.

Next is effect of density of air, again from equation 44, it is evident that is because we have seen the air density factor that corona loss is inversely proportional to delta therefore, equation 44 that is your peeks formula just now I showed you many times, it is evident that corona loss is inversely proportional to the air density factor that is delta, that is corona loss increases with decrease in air density factor your density to your what you call decrease of density of air.

So, corona loss of a high voltage transmission line passing through a hilly area may be higher than that of similar transmission line in plains due to the lower value of delta at high altitudes, but because when you are you know at higher altitude, but, because when your, you know at higher altitude, but in hill area, your what you call that your I mean dust or dirt whatever it is, it is hill area in altitude it will be less as compared to the plane areas.

So, that is why that similar transmission line in plains due to the lower value of delta at high altitudes, if delta is your low then your, what you call that corona loss is proportional to inversely proportional to delta. So, that is corona loss of a high voltage trans passing through a hill area may be higher because your delta your this thing, then that of similar transmission in plains due to the lower value of the delta at high altitude, so if that is the thing.

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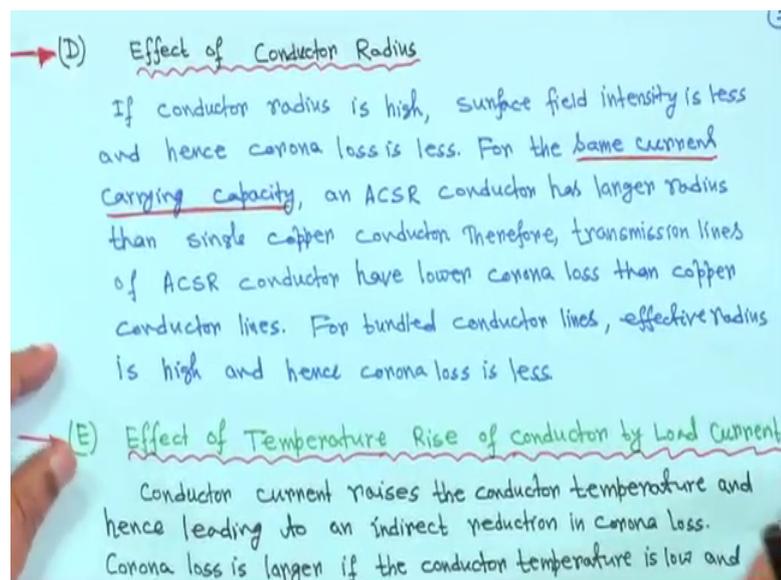
So next is, your I mean it is inversely proportional, if delta is high corona loss will be low, if delta is nearly 1 then corona loss will be your what you call low. Next is effect of conductor radius. Now, you know that conductor radius that potential gradient at the surface of the conductor is high if radius is your what you call small.

So, particular the, but anyway at the surface of the conductor is higher, we know that q upon 2 pi epsilon 0 into r. So, that means, if radius is high the surface field intensity is less, hence corona loss is less; for the same current carrying capacity say an ACSR your

conductor has larger radius then single copper conductor. Therefore, transmission line of ACSR conductor have lower corona loss then copper conductor lines, for bundles conductor lines effective radius is high, hence corona loss is less because if effective radius is high then potential gradient that will be also less. So, hence the corona loss is less, it is from your intuition you can come to this conclusion.

Now, other thing is that effect of rise of your what temperature rise of conductor by load current. When load is high, so conductor will carry more current; therefore, there will be temperature rise in the conductor, that means, the conductor current rises the conductor temperature hence leading to an indirect reduction in corona loss although, that is your although delta is related to your pressure as well as both temperature for computing that your this will critical voltage.

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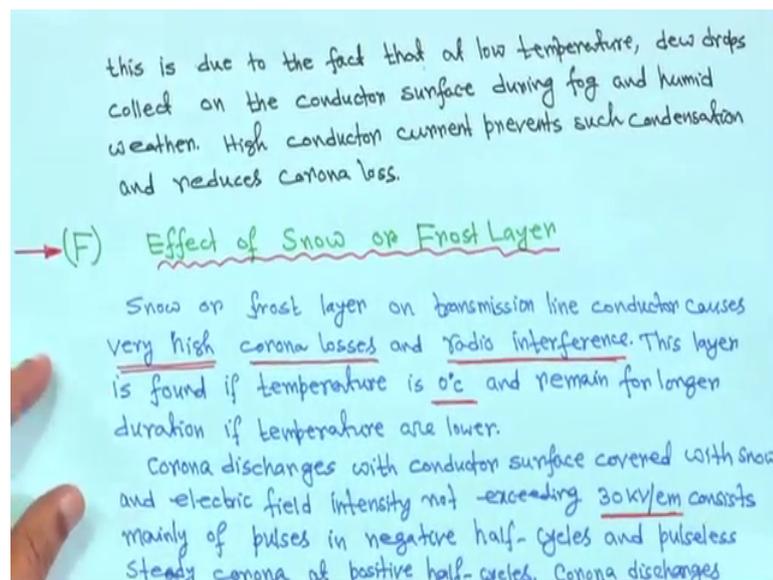
So, corona loss is larger if the conductor temperature is low and this is due to the fact that at the low temperature the dew drops collect on the conductor surface during fog and humid weather, high conductor current prevents such condensation and reduces corona loss. So, indirect effect is there for the your what you call the loading of the power system because if load is more than your conductor will carry more current.

Then, another thing is that effects of snow or frost layer, but particularly in that you know mountain side that effect of snow are will be there, it is very much there particular

in the hill areas. So, snow or frost layer on transmission line conductor causes very high corona losses and of course, the radio interference.

This layer is found if temperature is 0 degree centigrade and remain for longer duration if temperature are lower, I mean if it is 0 degree or below 0 degree that is minus temperature, hill area which is very common. So, this phenomena you will see that, that snow or your frost layer will be there on the conductor; overhead conductor.

So, corona discharges with conductor surface covered with snow and electric field intensity not exceeding 30 kilovolt per centimetre consists mainly of pulses in negative half cycles and pulseless steady corona at positive half cycles. So, corona discharges themselves which affect the form of snow layers are often blow off the snow in the neighbouring regions of corona, that means, suppose your, what you call it is high voltage line and that is conductor is covered by snow and if your what you call that corona the happens, then what will happen that due to this corona discharge that snow will melt in anyway, at the same time on the conductor nearby areas, nearby region of the conductor that snow will be blown off.

So, this is very common phenomenon and if you go to any hill area particularly an over a transmission line in winter, you can see that conductor is covered is you know by snow, this is very common phenomena and particularly this happens for your what you call for overhead conductor.

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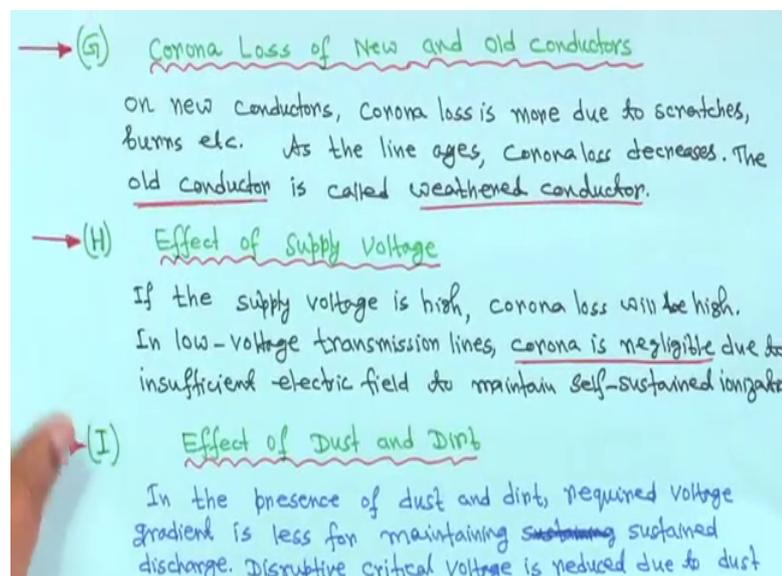
Next term is corona loss of new and old conductors. If the conductor is a new one, I mean suppose you are a putting a new transmission line. So, corona loss is more due to scratch burns etc for the new conductor, but over the time as the line ages corona loss decreases, the old conductor is called weathered conductor because it is sees conductor suppose it is there for few years, so it is called weathered conductors.

Once, 1 engineer asked me something like this, suppose your 3 phase line this is a question to you, 3 phase line; suppose out of this 3 phases say your putting 2 phases, suppose you are replacing 2 phases the old conductor say 10, 12 years old conductor, a new conductor and third one is a old one.

So, and it is a balance system, it is carrying equal power I mean balance system, supposed to carry equal current as well as your voltage also balance no question of unbalancing thing you take ideal case balance, then which conductors, so we will carry more power, the new conductor both new conductors or old conductor you as say it is a balance, this is a question to you; when you listen to this lecture you try to answer this question you send email and if you can correct answer I will appreciate that, I reply within 2, 3 days I reply whatever mails in the previous course I have received, I think I have answered to all of you, I did not leave anyone I gave all answers.

Next, effect of supply voltage; if the supply voltage is high, corona loss will be high this is very common, see supply voltage is high corona loss will be high; if low in low voltage transmission line corona loss is negligible due to insufficient electric field to maintain self sustained ionisation because at low voltage that is electric field intensity cannot be maintained, that is why corona loss it happens mostly 220 KV or above voltage level.

Particularly, now in rainy season if you I mean you can if you try to experience this, in rainy season if you see that overhead conductor say 220 KV line, you will find some kind of chattering noise, even in the daytime also that is that is mostly happening due to corona loss. Although, daytime that violet glow or visual glow may not be visible because daytime, but night time, it is possible and particularly in the dark areas those will be very prominent and this violet glow due to the ozone gas.

Then effect of dust and dirt, in the presence of dust and dirt, required voltage gradient is less for maintaining sustained discharge. So, disruptive critical voltage reduced due to

dust and dirt hence corona loss is more. So, if I mean if effect of dust and dirt actually it increases the corona loss.

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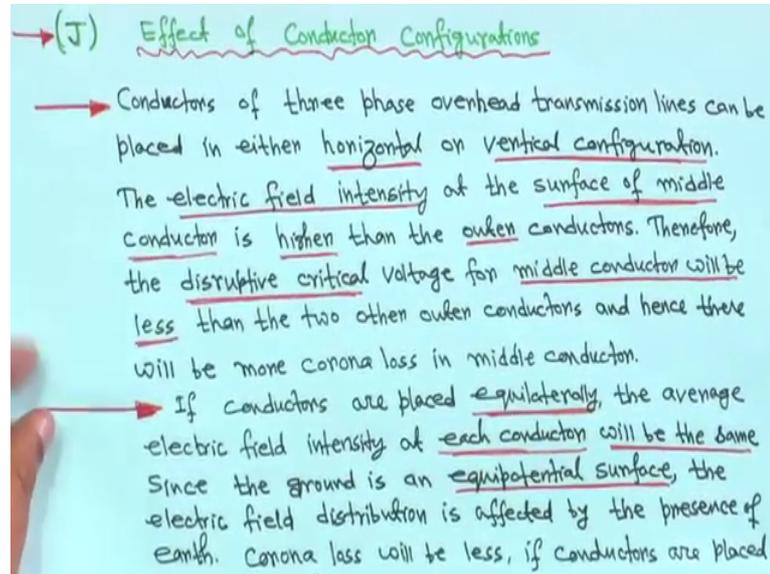
It makes your some for percentage of the total power loss of the transmission line, when you are calculating transmission line power loss this thing, those things are not considered. We considered for load class studies while doing it, you are making only higher corona loss, but we are not considering corona loss, but when the design the transmission line they consider all these factors.

Then, effect of conductor configuration, generally conductors are 2 types of configuration you know and 1 is horizontal another may be triangular or another may be vertical also, 3 conductors may be horizontal plane distance between AB BC, AB is D, BC is D, then AC will be 2 D, so horizontal plane symmetrical, similarly vertical also you can make it, another thing is the triangle either equilateral or may not be.

So, in that case what will happen? The conductors of 3 phase overhead transmission line it either horizontal or vertical configuration, first come to horizontal or vertical configuration. The electric field intensity at the surface of middle conductor is higher than the outer conductors, out I mean whether it is a vertical or horizontal 1 conductor will be there at the you know middle, ABC phase, so B is in middle and A B is in between A and C.

Therefore, the disruptive critical voltage for middle conductor, your, what you call disruptive voltage middle conductor will be less than the 2 other outer conductor. Hence, there will be more corona loss in middle conductor because the difference is V n and minus V 0. So, V n is actually line to neutral voltage and V 0 is disruptive critical voltage, so for the middle conductor if V 0 is less, then V n minus V 0 will be higher. So, naturally your, what you call that middle conductor your what you call hence there will be more corona loss in the middle conductor.

Because your V n minus V 0 will be your what you can high because V 0 will be less, that is why that the middle conductor is higher than your what you call the electric field intensity at the surface of middle conductor is higher than the outer conductors. Therefore, the disruptive critical voltage for middle conductor will be less, that is V 0 will be less, that means, V n minus V 0 square will be higher; therefore, the middle conductors your corona loss will be higher than the your what you call your hence there will be more corona loss in middle conductor than the outer 2 conductor, this is the reason.

Now, if conductors are placed equilaterally, say equilateral triangle the average electric filed intensity at each conductor will be the same because it is equilateral triangle, since the ground actually is at always equipotential surface, while computing is your what you call capacitor thing considering the effect of ground, in the capacitance chapter in power system analysis course all that we have discussed this. If you want to grasp your memory just I request please go through that your what you call that chapter, that capacitance chapter.

Therefore, the electric field distribution is affected by the presence of the earth, corona loss will be less. If conductors are placed your what you call at more high, but if you that means, the tower height will be more, but if you increase the tower height, then your what you call the cost will be more because construction of the your tower of the cost will be higher, so some optimum design is required. So, these are general phenomena.
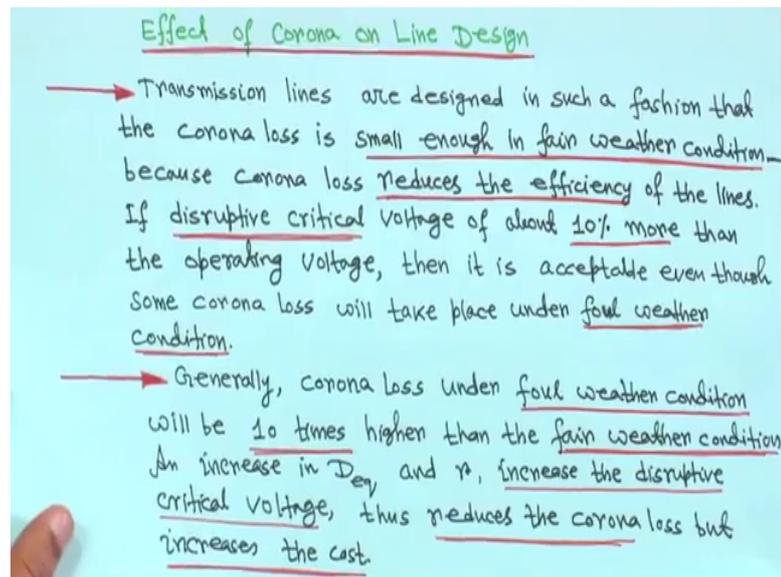
Next is the effect of corona on line design; now, transmission line are designed in such a fashion that the corona loss is small enough in fair weather condition that is true. If you design a transmission line if corona loss is higher in fair weather condition that is not acceptable, but because corona loss reduces the efficiency of the line because when you are considering for computing the efficiency of the line and that time we will consider losses, so during fair weather condition that the corona loss should be low.

If the disruptive critical voltage of about 10 percent more than the your operating voltage, then it is acceptable even though some corona loss will take place when foul weather condition, I mean if your disruptive critical voltage 10 percent more than the operating voltage then still it is acceptable, even though some corona loss will take place under foul weather condition.

Generally, corona loss under foul weather condition will be as many as 10 times higher than the fair weather condition. So, when normal temperature or your normal weather, there will be no rain, no snow fall nothing is there and the in fair weather condition, in that case corona loss will be low, but foul weather condition it increases actually that is why I am telling you during rainy season another thing we will see corona loss increases and other thing is an increase in Deq and r, increase the disruptive critical voltage because it depends on the natural log or log base 10 that is ratio Deq upon r, thus reduces the corona loss, but increases the cost.

So, because if you try to increase the radius, naturally the conductor diameter will be more, then value will be more and at the same time your cost will increase, but there are many other issues with the increase of this thing radius of the conductor or diameter of the conductor because when it go for sag and tension and analysis at that time we will see that. So, these are the some of the your what you call that effect different type of parameters effect the corona we just discuss. So, this chapter is very interesting and easy.

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Next, we will take your example say this is example 1. So, here they look conductors of a 3 phase transmission line are equilaterally spaced say 6 meter apart, the radius of each conductor is given 1 centimetre, the air temperature is 30 degree Celsius and pressure is 740 millimetre of mercury.

So, if surface factor is 0.83 and irregularity factor is 0.92, you have to calculate the disruptive critical voltage and visual critical voltage all right, this is the thing. So, all parameters from equation 43, your density factor delta is 0.392 p divided by 273 plus t. So, t is, p is given 740 millimetre and t is equal to 30 degree Celsius substitute you will get delta is equal to 0.957, that is the your density factor.
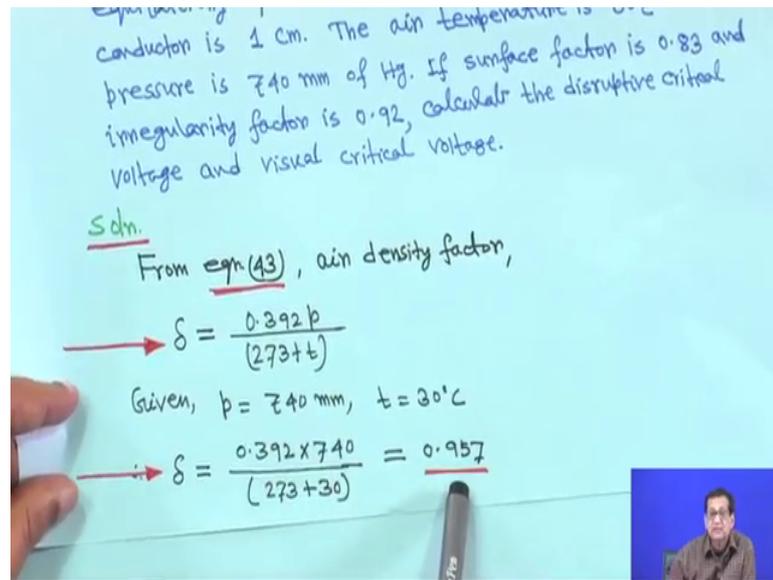
Next is, now another thing is that next from equation 40, disruptive critical voltage, that is V 0 is equal to 3 into 10 to the power 6 upon root t sorry root 2; r delta m 0 ln Deq upon r volts. Now, data given m 0 is given 0.92, delta just we have computed 0.957, r is equal to 1 centimetre is equal to 0.01 meter and as equilaterally space is 6 meter is, sorry, so, Deq actually 6 meter.

So, V 0 is equal to 3 into 10 to the power 6 by root 2 into r 0.01 into delta 0.957 into your m 0 0.92 ln 6 upon 0.01 volts, if you compute this V 0 will be 119.475 KV, it is r m s value because we have taken this r m s value divided by root 2.

Now, from equation 42, visual critical voltage, this is the formula for visual critical voltage V suffix v is equal to 3 into 10 to the power 6 upon root 2 that we have seen earlier, it is mv into r into delta in bracket; 1 plus 0.0301 upon root over r delta ln Deq upon r volts. So, this is your visual, now we have to substitute all the date mv r delta everything is given, Deq r everything is known.

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So, if you put that the Vv is equal to 3 into 10 to the power 6 upon root 2 into 0.83 into point 0 1 into 0.957 in bracket 1 plus 0.0301 root over your r delta, r is 0.01 and delta is 0.957 ln 6 upon 0.01, if you compute this one, then Vv will be 140.95 KV, this is the r m s value. So, visual critical voltage and disruptive critical voltage we got.

Next 1 is a example 2, this is example 2.

A 3 phase 220 KV, 50 hours, 200 kilometre long transmission line consist of 3 standard aluminium conductors, spaced triangularly at 4.8 meter, radius of each conductor is 1.5 centimetre, the air temperature is 27 degree Celsius and pressure is 740 millimetre of mercury.

If the breakdown strength of air is your 21.1 KV r m s, this r m s value is given per centimetre and the surface factor is given 0.85, compute disruptive critical voltage, also determine the visual critical voltages for local and general corona, if the irregularity factors are 0.72 and 0.8 for visual corona local and visual corona general respectively. So, these are the things given that you have to find out. So, we will be back soon.

Thank you.