Power System Analysis
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Lecture - 04
Resistance & Inductance

So, next are disadvantages of low power factor.

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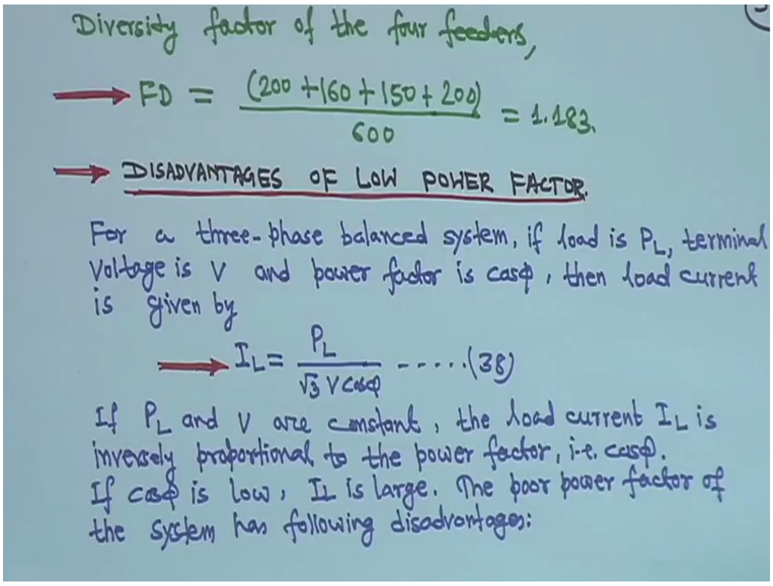

So, what are the disadvantages? For a three-phase balance system, for example; say if load is P L say some terminal voltage is V and power factor is cos phi, then load current is given by I L is equal to P L upon root 3 V cos phi. This is equation 35. Now if P L and V if both are constants say then the load current I L is inversely proportional to the power factor- if P L and V both are constants. That is phi constant cos phi is constant, if cos phi is low then I L is large if P L V constant. Then cos phi is low, so I L will be large. The poor power factor of the system has the following disadvantages.

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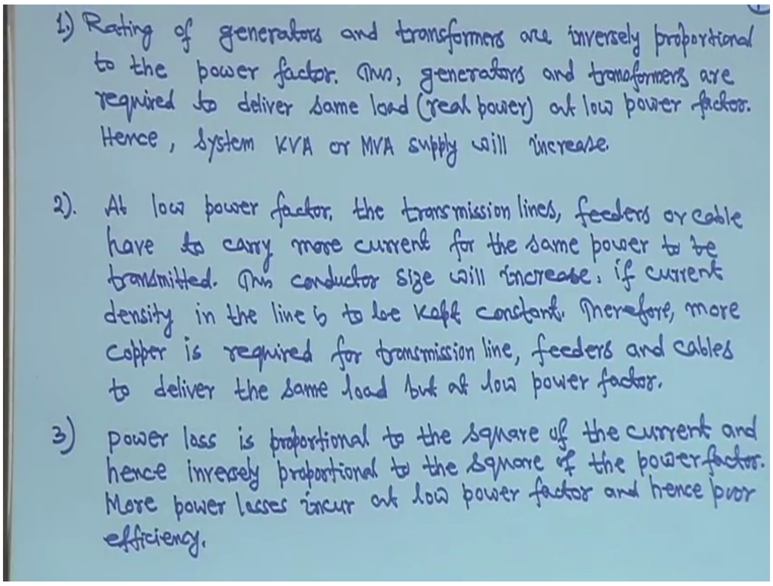

So, this is for first couple of hours this is for your some general ideas of the system or power factor. Now number one: the rating of generators and transformers are inversely proportional to the power. Thus generators and ran transformers are required to deliver same load that is real power at low power factor if power factor is poor. Hence, system KVA or MVA supply will increase, because if power factor is poor although to supply the same real power that KVA or MVA supply will increase because reactive power will increase. Hence, many many other things are associated with that later we will discuss.

At low power factor the transmission lines feeders or cable have to carry more current for the same power to be transmitted. Because of poor power factor more your what you call reactive power has to flow through the line. So, thus conductor size will increase because current will increase, therefore ampacity of the conductor will increase conductor size will increase. If current density in the line is to be kept constant right, therefore at low power factor the transmission lines feeder or cable will have to carry more current for the same power to be transmitted.

Thus conductor size will increase. If current density in the line to be kept constant, therefore more copper is required to for transmission lines feeders and cables to deliver the same load but at low power factor. Then we get low power factor current will be high, therefore the conductor size will increase, therefore this if conductor size increases is you did if you did more volume of the copper will be required. So, that way I will explain. If it is now conductors are (Refer Time: 03:26) are conductor right all these things are there, but volume of the conductor will increase right for the same load to be transmitted. Therefore, power factor is an poor power factor has lot of disadvantages.

Number 3 is power loss is proportional to the square of the current and hence inversely proportional to the square of the power factor. So, more power losses incur at low power factor and hence poor efficiency. That means, transmission line efficiency will be poor because line current will increase and therefore power loss will increase. So, this is number 3.

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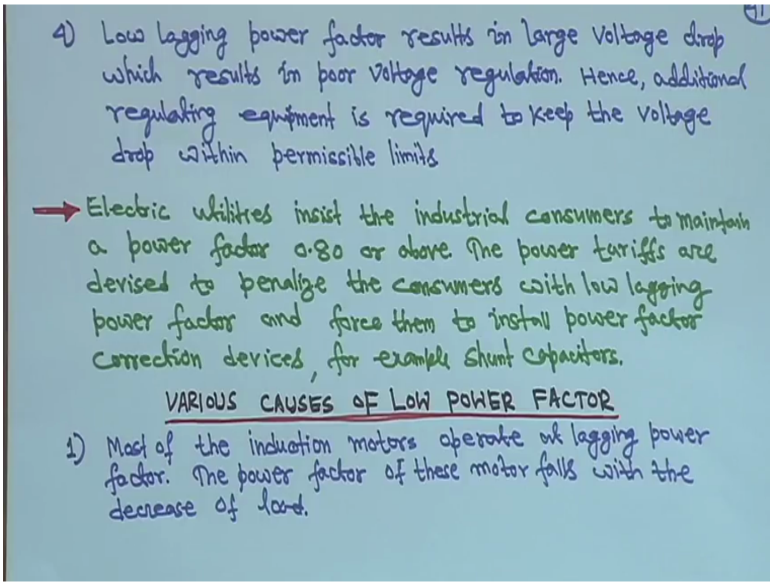

And number 4 is low lagging power factor result in large voltage drop, which result in poor voltage regulation. Hence additional regulating equipment is required to keep the voltage drop within permissible limit. So, all these are the disadvantages of poor power factor. We always want that for any system it should operate at unity power factor perhaps reality it may not be possible, but we want that. So, electric utilities insist the industrial consumer, particularly industrial consumers to maintain the power factor 0.8 or above. In industry they have different parts of tariff right, sometimes they charge they charge on kilowatt demand, KVA demand they have two part or three part tariff. If your power factor is poor then KVA demand will be more, then more tariff based on KVA demand also they charge utilities they charge from the industry on KVA demand. That is why they have to improve the power factor.

So, the power tariffs are devised to penalize the consumers with low lagging power factor and force them to install power factor correct correction devices. For example, some capacitor, that if your power factor is poor you will draw more KVA from the utility. And in this case you have to pay more money because they have a two part tariff the charge on your maximum KVA demand also. If your KVA demand is less means power factor is better. Or KVA demand is more means power factor is poor. So, that is why they will always try to see that KVA demand is less, because they one part of that tariff is based on their kilo volt ampere or KVA demand.

Now various causes of low power factor: most of the induction motors operate at lagging power factor. The power factor of these motors falls with the decrease of load. This is one reason.

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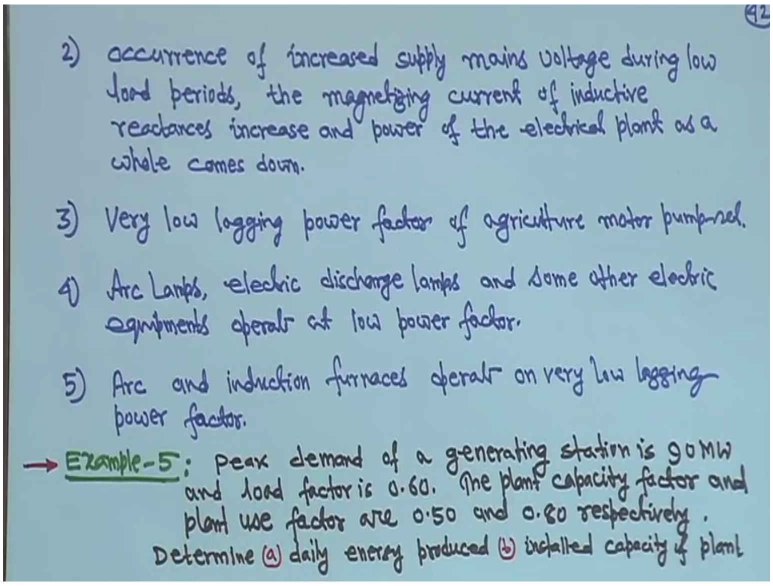

Then second one is: occurrence of increase supply main voltage during low load period. The magnetizing current of inductive reactance increase and power of the electrical plant as a whole comes down; it is actually power factor. Third one is: very low lagging power factor of agriculture motor pumpset. Agricultural motor pumpset they operate at very low power factor, I mean very poor and because of that also sometimes agricultural motor pump sets also you will find that frequent working of the winding fault will be there. Then arc lamps, electric discharge lamps, and some other electric equipments operate at very low power factor. Arc and induction furnaces operate on very low lagging power factor.

So, these are some of the equipment they operate at very low lagging power factor. These are some of the, so what you call they are common reason for low various cases for low power factor. Next will take another example: a peak demand of a generating station is 90 megawatt and load factor is 0.6: the plant capacity factor and plant use factor are 0.5 and 0.8 respectively. This plant capacity factor and plant use factor earlier we have discussed. Determine daily energy produced b installed capacity of plant.

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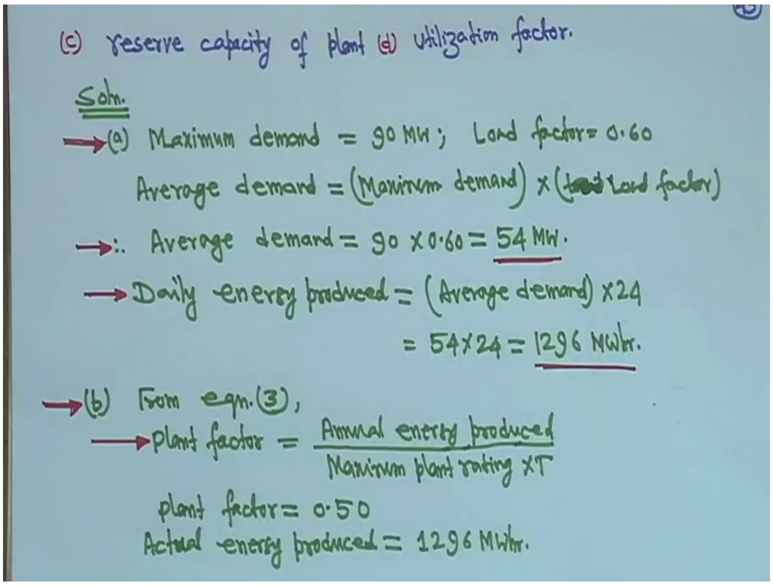

And c, that reserve capacity of plant and d utilization factor. These four things we have to obtain daily energy produced, then installed capacity of plant, then reserve capacity of plant, and d utilization factor. So, solution maximum demand is 90 megawatt, this is given maximum demand is given 90 megawatt and your load factor is given 0.6 that is also given. Therefore, average demand is equal to maximum demand into load factor, so average demand is 90 into 0.6 hence 54 megawatt this is the average demand. Now daily energy produced is equal to average demand into 24 hours in a day. So, 24 that is 54 into

24 it is equal to 1296 megawatt hour.

So, from equation 3 now plant factor is equal to this part b, but b we have to find out installed capacity of plant. Now plant factor is equal to annual energy produced divided by maximum plant rating into the time; plant factor is given 0.5 it is given and actual energy produced already you have got it 1296 megawatt hour this also you have got it. Therefore, maximum plant rating it is 1296 right divided by 0.5 into 24 is equal to 108 megawatt.

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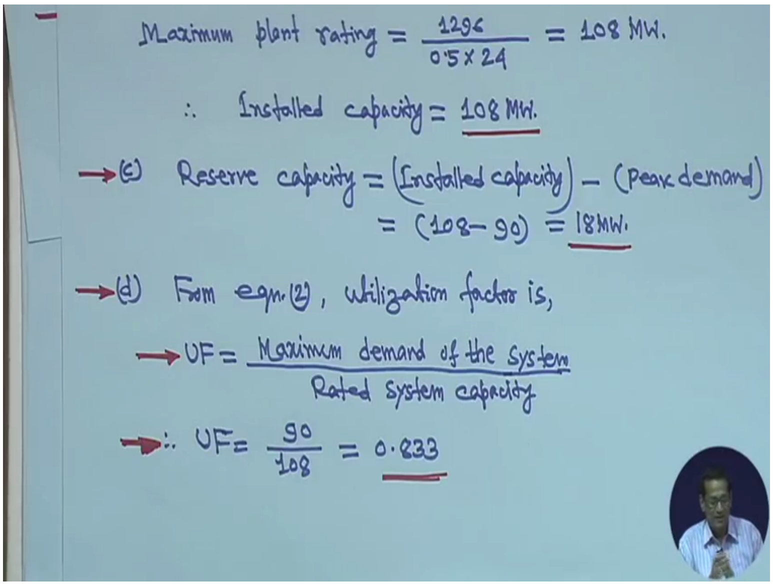

This is the plant rating. Therefore, plant rating is equal to installed capacity. So, installed capacity is 108 megawatt.

Now part c reserve capacity is equal to installed capacity minus peak demand. Installed capacity is 108 megawatt and peak demand is 90 megawatt that is already given, peak demand is given 90 megawatt, therefore 108 minus 90 that is 18 megawatt. And from equation 2 utilization factor UF is equal to maximum demand of the system divided by rated system capacity. Maximum demand is 90 megawatt and rated system capacity it is installed capacity that is the same thing, that is the rated system capacity 108 megawatt so utilization factor is 90 divided by 108 that is equal to 0.833.

So, this is the general. So some examples; some 4-5 examples standard examples we have taken for these you know that introduction part all together structure of power systems and few other aspects. So, from this sums we have some general ideas regarding the different terminology, regarding transmission, generation transmission, and distribution systems. Plus we have seen that relationship between load factor and loss factor that how direct it is not possible, but some relationships has been established. And those formula for relationship between loss factor and load factor are commonly used. And some general ideas you have regarding different type of load factor, loss factor, utilization factor, coincidence factor, then demand factor, then diversity factor, all this terminology in the beginning we have used. And after this we will start for this thing is that that what you call that resistance, inductance, capacitance of the transmission line.

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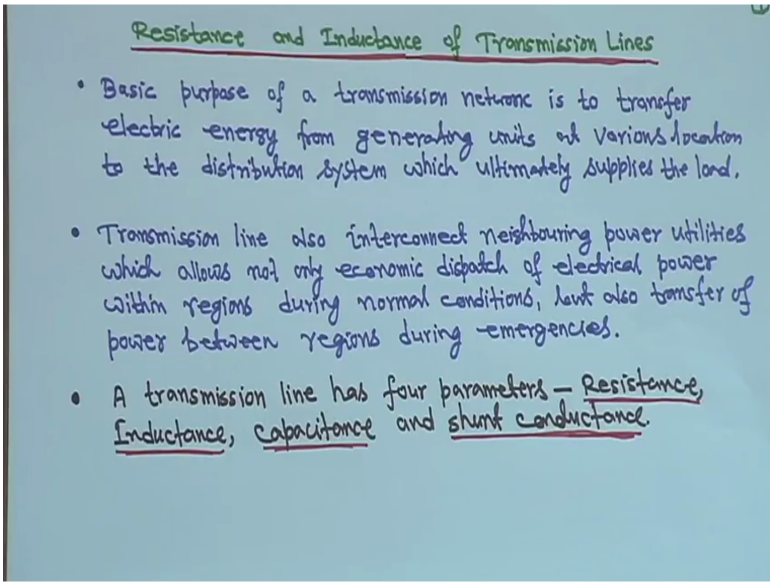

First we will see that resistance, then we will see that your what you call inductance, and then will see the capacitance of the this thing transmission line. So, these are the common thing for this power system course. And so first thing is that will start from the this thing that resistance and inductance of transmission lines after that we will see that your what you call that capacitance.

So, basic purpose of a transmission network is to transfer electrical energy. That we have seen these thing we have the previous thing from generating units at various locations to that distribution systems which ultimately supplies the load. So, transmission system actually transmits power from the generating to the consumer distribution side. So, transmission line also interconnect neighboring power utilities, just we have discussed before which allows not only economic dispatch of electrical power within regions during normal conditions, but also transfer of power between regions during emergencies. So, this is that interconnected operations we have seen before, that how actually different areas are interconnected, how it will be useful that reasons for interconnections.

Basically a transmission line has four parameters: resistance, inductance, capacitance and shunt conductance. These four parameters are there for transmission system a transmission line. So, generally your resistance is a important part of a transmission line, because it consumes a copper loss I square r; that is the major thing. So, resistance here are important.

And for transmission system that for different your what you call different voltage levels the different type of conductors are used. Particularly for transmission system I can recall all sort of thing that you will find the conductors names (Refer Time: 14:28) name of the animals, like zebra, then tiger, then your wolf that different name of the different animals; those conductors. And it depends on the voltage levels different conductors has different resistance per ohm per kilometer and as well as that reactance.

So, while of course, it has a bundled conductors are there, double circuit lines are there, different type of when you have seen that high tension transmission line. We have seen in each face you may have 2 or 3 or even more conductors, bundle conductors are there, sometime single conductors are there in each phase. So, all these things your this resistance depends on the your of course it depends on the type of the material whatever used for the conductor and its cross sectional area, because we know r is equal to resistance is equal to rho into (Refer Time: 15:59) upon a is the cross sectional area of the conductor.

So, if I recall correctly the resistance of course it depends on the cross sectional area. If you have a very large if the cross section of the conductor is large right then r is equal to rho l by a. So, later the resistance will be lower. But in the case of reactance resistance in a very in a 33 KV to 400 KV transmission lines resistance are different, they are totally different I mean quite lower value to higher, higher value to lower, lower value from low voltage to high voltage. Where is in the case of inductance and hence the reactance whenever we try to compute I was making some computation I found that reactance part; generally V with voltage level from 33 KV to say 400 KV reactant (Refer Time: 16:33) it will find varies in between 0.26; 0.26ohm per kilometer to 0.34 or 0.35 ohm per kilometer. This way more or less it varies. For a resistance where resistance various is much more for your transmission line; so later will try to see.

So, this shunt conductance actually we have told three parameters: for resistance, inductance, capacitance, and shunt conductance.

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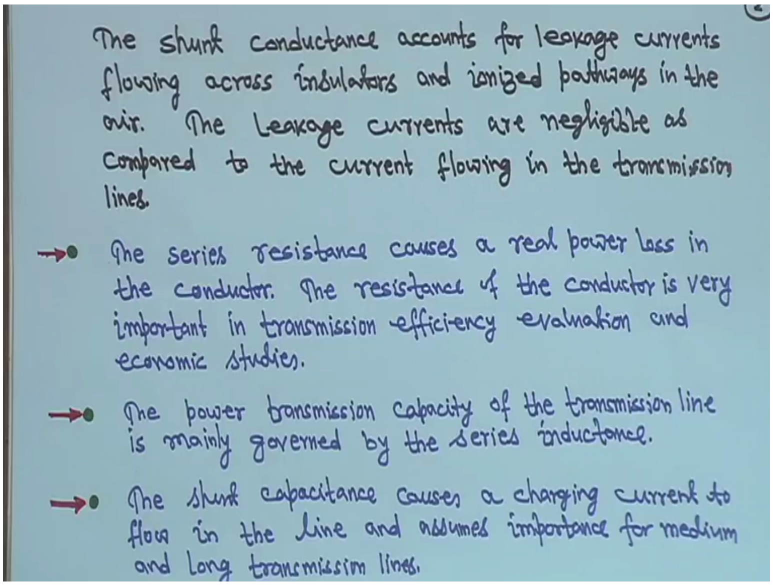

So, shunt conductance actually accounts for leakage current flowing across the insulators, and ionized path wise in the air. But these leakage currents are negligible as compared to the current flowing in the transmission lines. So, this shunt conductance theme will not considered for this our study, but for the sake of clarification basically for transmission line we consider four parameters: so resistance, inductance, capacitance, and your conductance. So, it is for across the insulator it may happen and ionized path wise in the year. But the series resistance causes a real power loss in the conductor, because I square loss r loss will be there. So, resistance of the conductor is very important in transmission efficiency evaluation and economic studies, because if resistance is more than power loss will be more. So, this is very important.

Second thing is: the power transmission capacity of the transmission line is mainly governed by the series inductance a x. For a transmission line if you see that r by x ratio is quite small or other x by r ratio is quite high. Therefore, your power transmission capacity of the transmission line is mainly governed by the series inductance. And third point is the shunt capacitance causes charging current to flow in the line and assumes importance for medium and long transmission line long overhead lines.

If it is a cable then perhaps at low voltage level 11 KV also you have to consider the charging current you cannot ignore. But for overhead transmission line this charging a your shunt capacitance upto 33 KV level you may ignore, but 66 even 33 KV people are considering it, but if it is 66 KV or above you have to consider the your shunt capacitance. But if the distribution side at 11 KV site there is no need to consider the for overhead distribution; overhead 11 KV distribution system there is no need to consider the your charging capacitance or shunt capacitance. But for cable you have to consider; even it is 11 KV also you have to consider; because their charging capacitance is quite I mean it has a significant value. You cannot you cannot ignore that.

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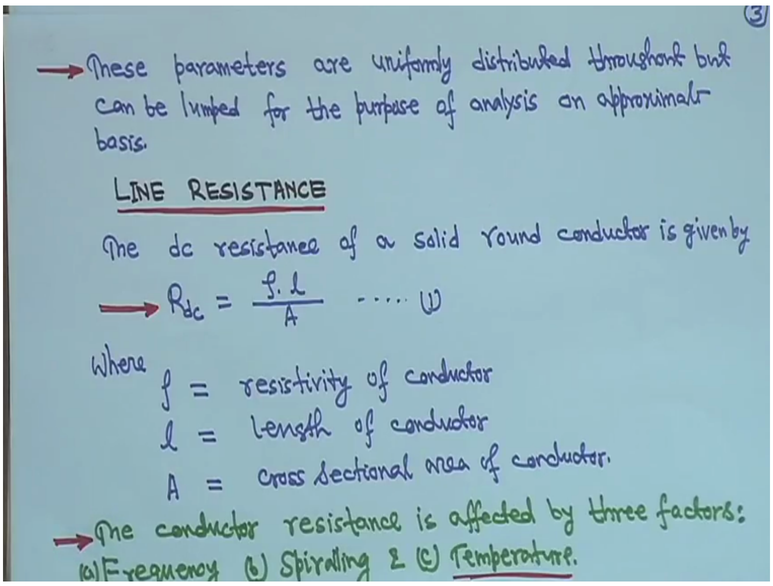

So, these parameters are uniformly distributed throughout, but can be lumped for the purpose of analysis an approximate basis. Actually transmission line you have seen these parameters are uniformly distributed, but for our understanding and for our analysis will consider they can be lumped for the purpose of analysis an approximate basis. So, this way we will analyse. For example, let us start from the line resistance.

Generally the dc resistance of a solid round conductor is given by we put R dc is equal to rho into l upon A. This is equation 1, because this is a second topic so this is again equation 1. Rho is equal to resistivity of the conductor, l is equal to length of the conductor and A is equal to cross sectional area of the conductor. So, the conductor resistance is affected by three factors: one is the frequency, second is the spiraling, and third is the temperature. This three factors basically affects the conductor resistance. And this is basically a dc resistance R dc is equal to rho into l by A.

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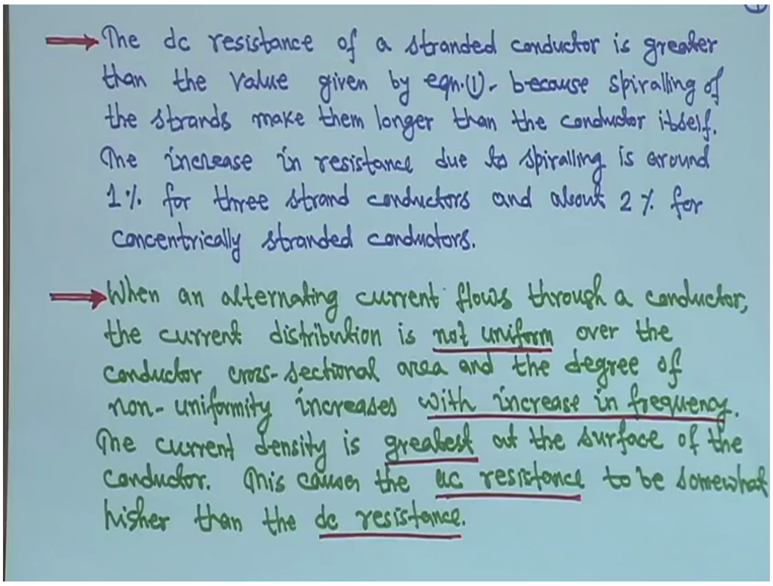

So, the dc resistance of a standard conductor is greater than the value given by equation 1. Because spiraling; actually if you look at the transmission (Refer Time: 21:41) conductors they are actually your spiralling of the strands make them longer than the conductor itself. It is not a solid round conductor, it is conductor if it is stranded conductor and because of spiralling that actual length is slightly or longer than the conductor itself. This increase in resistance due to spiralling is around 1 percent for three strand conductors and about 2 percent for concentrically stranded conductors; solittle bit higher. But 1 percent, 2 percent is not that very high, but you have to consider.

Now when an alternating current flows through a conductor the current distribution is actually not uniform. For dc current the current distribution is uniform right over the conductor cross sectional area and the degree of non uniformity increases with increase in frequency. Actually if it is a dc current no there is suppose cross-sectional area is say 5 centimeters square for a very large of course, 5 centimeter square and say 5 ampere current is flowing. So, current density will be 5 5 5 1 ampere per centimeter square. And it is uniform for dc current.

But when alternating current or ac current flows right through a conductor the current distribution is not uniform, over the conductor cross sectional area. And the degree of non uniformity increases with increase in frequency. And this will see later on when you will study this inductance. The current density is greatest at the surface of the conductor this causes the ac resistance to somewhat higher than the dc resistance. And this effect is called as skin effect. When you will study inductance at that time will see what is skin effect right. That means, at every point of that cross section the current density is not uniform for your these thing, for a alternating current; current density is different.

That means this source that ac resistance is higher than the dc resistance.

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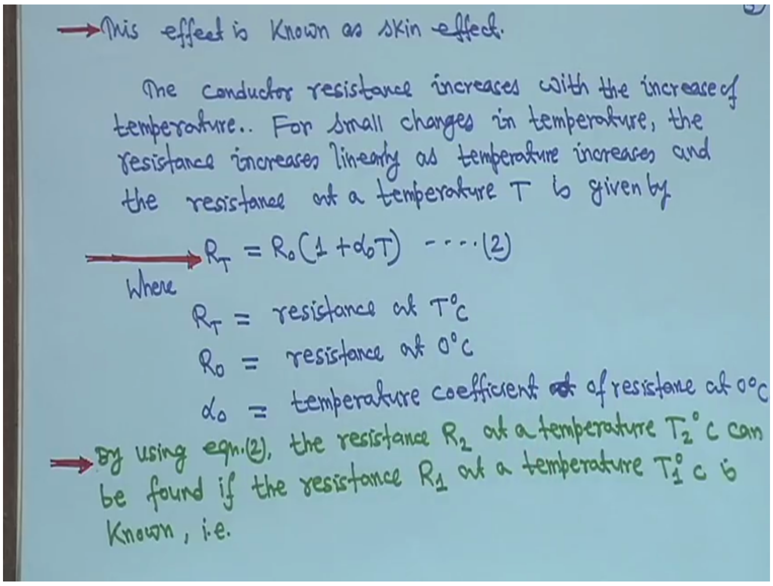

So, this effect actually is known as Skin Effect. So, the conductor resistance increases with the increase of the temperature. You know that if temperature varies then conductor resistance also will increase. For small changes in temperature the resistance increases linearly as temperature increases. If temperature changes is small the resistance will also this thing increase your what you call linearly. And the resistance that of temperature T is given by you know this R T is equal to R 0 1 plus alpha 0 into T: this is equation 2.

Where R T is equal to resistance at T degree Celsius these are all basic thing and R 0 is equal to resistance at 0 degree Celsius and alpha 0 is the temperature coefficient of resistance at 0 degree Celsius. So, by using equation 2 the resistance are 2 at a temperature T 2 degree Celsius can be found.

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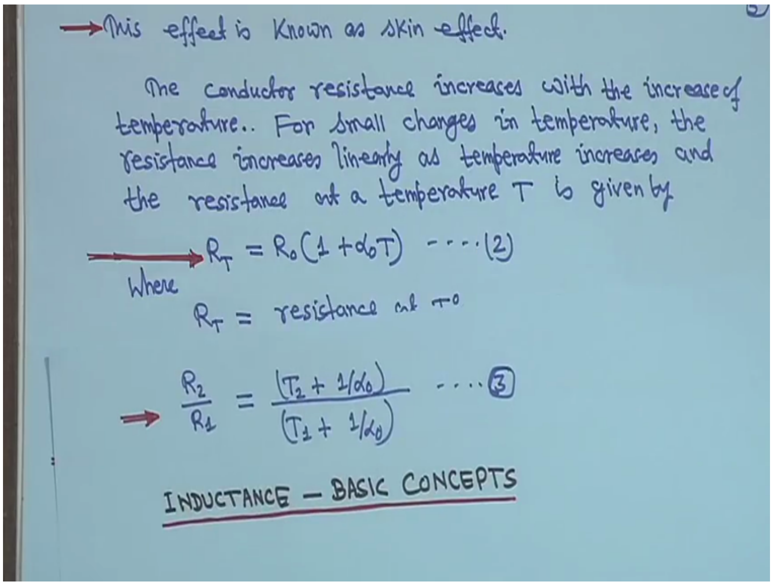

If the resistance R 1 at a temperature T 1 degree Celsius is known that R 2 upon R 1 is equal to T 2 plus 1 upon alpha 0 divided by T 1 plus 1 upon alpha 0, then see if you know the resistance R 2 at temperature a T 2 degree centigrade can be found if the resistance; R 2 can be found at T or temperature T 2 if the resistance R 1 at temperature T 1 if it is known to you. So, what will do from this relation? We will write one equation R 2 is equal to R 0 plus 1 plus alpha 0 you are T 2 another one will write R 1 is equal to R 0 1 plus alpha 0 T 1 and (Refer Time: 26:05) then you will get R 2 upon R 1 is equal to T 2 plus 1 upon alpha 0 upon T 1 plus 1 upon alpha 0.

Now this is that your, what you call this is the resistance. Although will study everything slowly and slowly and I believe that many of you have studied these, inductance, capacitance all these things. So, during this time apart from of course next will come inductance; after that capacitance and after that that medium line long line short line, but before that I am giving one exercise to all of you and you try to do these.

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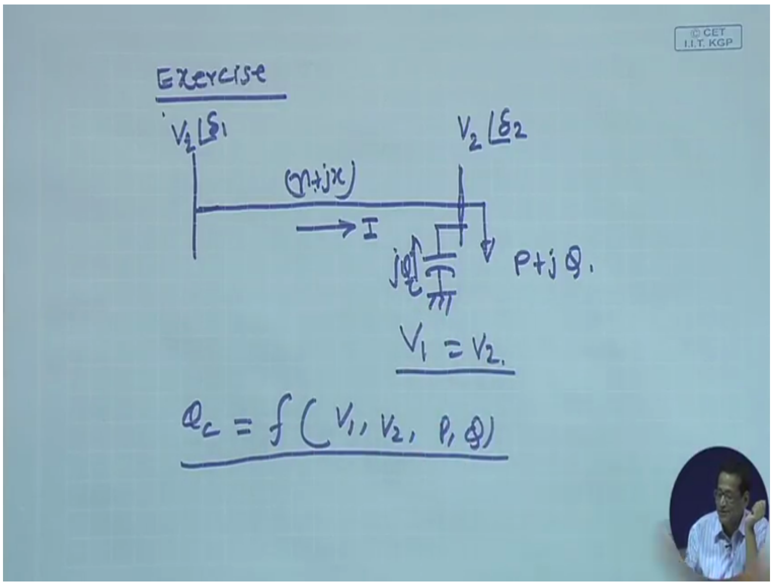

For example: this is an exercise for you. Suppose you have all these things will study, but in advance I am giving. Suppose you have a transmission line this side is sending end, this voltage is say V 1 angle delta 1, this side is receiving end is sending end voltage V 2 delta 2, this impedance of the line is r plus j x, current flowing through this line is I and here you have load P plus j Q; this is the load.

Now, I am not writing anything but my recorded voice you can make out. Now my objective is I want to maintain this V 1 and V 2; this is voltage magnitude, V 2 voltage magnitude I want to maintain my V 1 must be equal to V 2; I want to maintain that. For which I have to connect a shunt capacitor here which is injecting that say Q c i put j Q c which injecting a your what you call a reactive power here right- to maintain voltage. Initially when p when it was not there V 2 was say V 2 was less than V 1 it is a lagging load. So, V 2 was less than V 1 current is flowing in this direction. Now as soon as I put some value Q c here I want to maintain V 1 is equal to V 2. Then I want to find out Q c in terms of I made function of in terms of V 1, V 2, P and Q. Delta has to eliminated there should not be any delta in mathematical expression, I want to find out Q c must be function of V 1 V 2 P and Q.

Only given hint is that your Q c when you will try to find out it will be quadratic equation of Q c. There will be two solutions for Q c: one is feasible and other is not feasible, but both the solution will be function of V 1 V 2 P and Q, but one is feasible other is not feasible.

So this exercise I am giving you and those will take this course this is an exercise if you can do this of your own. I will solve it, but before those video lecture when you will see; before that if anybody can do it and can show this to me then I will appreciate that. So, this is very interesting problem.