Power System Engineering

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Lecture - 42
Application of capacitors in distribution system (Contd.)

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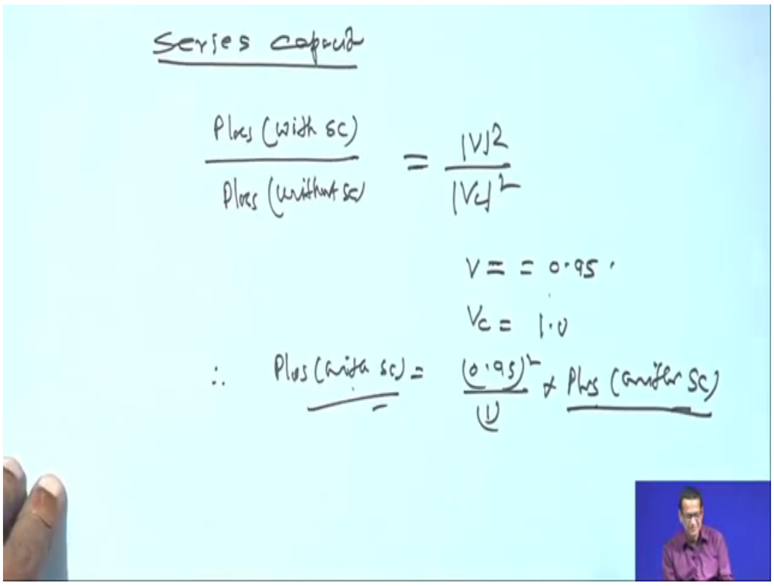

So just before taking few examples let us summarize about per series capacitors right. What we have studied? Before taking the example it will find some interesting things. So, series capacitor when you do that is your power loss, that is without your what you call with series capacitor divided by power loss right, without series capacitor these actually it is in actually it is inversely proportional to the square of the voltage magnitude. So, we got this one V square upon V c's square right this one we got.

So, just for the purpose of this thing suppose before capacity this is V is the that without capacitor that is why writing V, suppose it was 0.95 right and suppose after placing capacitor you got 1.0 this is just an understanding; that means, Ploss with series capacitor will be it is V is equal to 0.95 square voltage are improve because of capacitor is one into your Ploss without series capacitor because it is inversely proportional.

So, naturally point 9 5 square whatever we will come, so right. So, that much of it is without series series capacitor right and with series capacitor point 9 5 square whatever it will it will come right, so multiplied by this thing.

That means with series capacitor power loss actually it all though not much, but to some extent it actually power loss it reduces the power loss this results. This simple example I am giving and that is why we have got this formula Ploss without SC by Ploss your with SC by without SC is this much right because it improve the voltage level this is for series capacitor.

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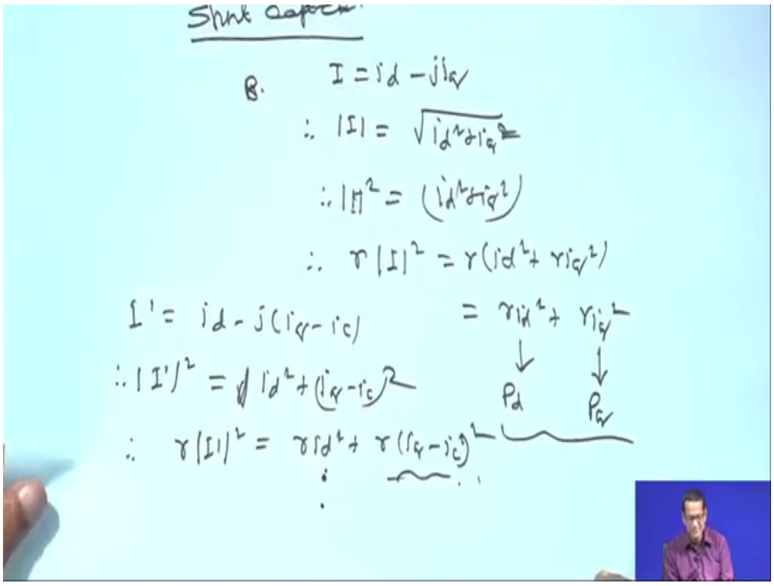

Just and for the shnt capacitor what we got, we got for shnt capacitor right shnt capacitor right. What we got that without anything without anything if current is say I equal to id minus j i Q they needs magnitude I is equal to root over id square plus i Q square right.

That means, this one is equal to id square plus i Q square right and power loss say real power loss multiplied by r. So, r I square right is equal to r into id square plus r i Q square is equal to your r id square plus r i Q square. This part we are calling if you call it as a this pack as a d d x is components say this part is P d and this part is P Q right.

So, this way if you made right, so and if you put the shnt capacitor there at that time current is coming id minus j i Q minus I C right therefore, magnitude of this one I dash square is take magnitude then square it will be your id square plus i Q minus I C whole square right.

So, its power loss will be then r id square is equal r I dash square is equal to r id square plus r i Q minus I C square whole square right. So, that means, it reduces the power loss it directly it what you call it directly your what you call reduces that reactive component of the current. So, this part I told you i Q if you made i Q is equal to I C then your what you call this your this part will remains same this may be 0, but this part will almost unchanged. This is the inherent property of the circuit this cannot be made to 0, right. So, this loss will remain in the circuit whether it is directed.

Similarly if you multiply x, so x into id square also will remain in the system that is the reactive component right, but this part if you make it vanish that x into plus x into i Q minus I C square, so this is one thing.

Another thing is that shnt capacitor do not merge it improves the voltage magnitude level therefore, same philosophy that is Ploss right with writing full form with let us s h is shnt shnt capacitor then Ploss that without shnt capacitor is inversely proportional loss is inversely proportional to the square of the voltage magnitude.

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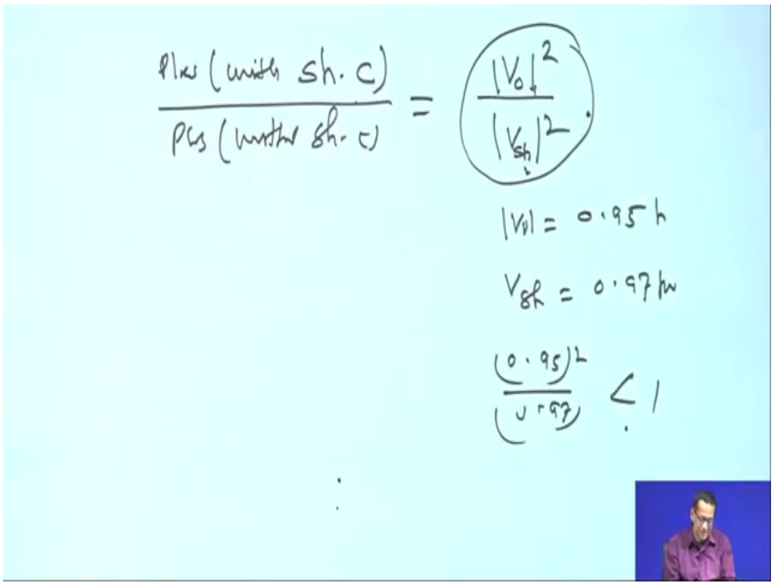

So, this one can be made as suppose it is V 0 magnitude that is without voltage without shnt capacitor and it is this is say your V sh that is with your what you call shnt capacitor because of shnt capacitor voltages are improve and this is your V 0 right. For example, if say V 0 is equal to say 0.95 and suppose your V sh supposed due to your shnt capacitor supposed voltage has improved 2.97 right therefore, 0.95 square by 0.97 square it will be less than 1, right.

That means Ploss is some less than one means some point something will come 0.9 something will come say right. So, in that case that due to shnt capacitor also voltage power loss also reduced to some extent right because this term will be your what do you call less than less than 1.

But if you, but some cases some cases in distribution system if there are some nodes it may happen that it is large network of course, some nodes it may happen that sending and receiving an voltage is slightly greater than sending an voltage these may also happen, but that is may be in a large network may be 2 3 nodes it may happen right. But otherwise that shnt capacitor also improves the your voltage level, so it also reduces the losses.

But not like series capacitor because series capacitor case this voltage rise is very high right. So, these are some general ideas for series and shnt capacitor right that how things are now, let us take the example.

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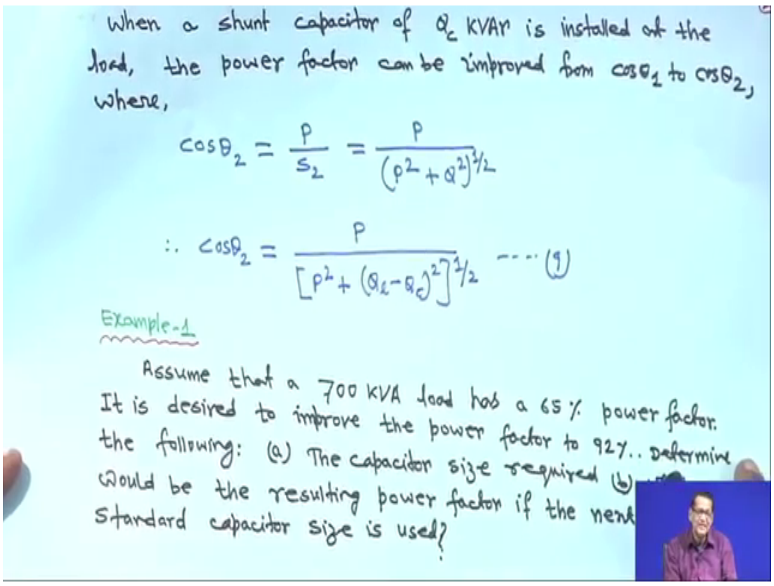

So, assume that a 700 KVA load has a 65 percent power factor is cos pi cos theta is equal to 0.65 it is desired to improve the power factor 2.9 to that is 92 percent means 0.92 determine the following the capacitor size required. What would be the resulting power factor if the next higher standard capacitor size is used?

Actually in market if you ask for a give your capacitor of 337 kilowatt or 425 twenty 3 kilowatt or 405 kilowatt, it is not available. Some standard ratings of capacitors are available in the market, like 25 kvr, 50 kilo kvr, 65 kilowatt, then 100 kilowatt, 200 kilowatt like that. If you take a 75 kilowatt also sometimes available, but if it is not available then for a safety use 125 kilo hour, 150 kilo hour bank, right.

So, this way combination, so if that is 700 kvr load is there 0.65 power factor to be into 90 percent, 92 percent, so 0.92. So, you have to determine the capacitor size required and what would be the resulting power factor if the next standard I mean whatever capacitor size is required means.

Suppose you have got some value say 331, but this is not available, so nearest rating will be either 325 you take or 330 you take, but 331 cannot accordingly you have to see how your things are and if you use that new side you find out what is the power factor, right.

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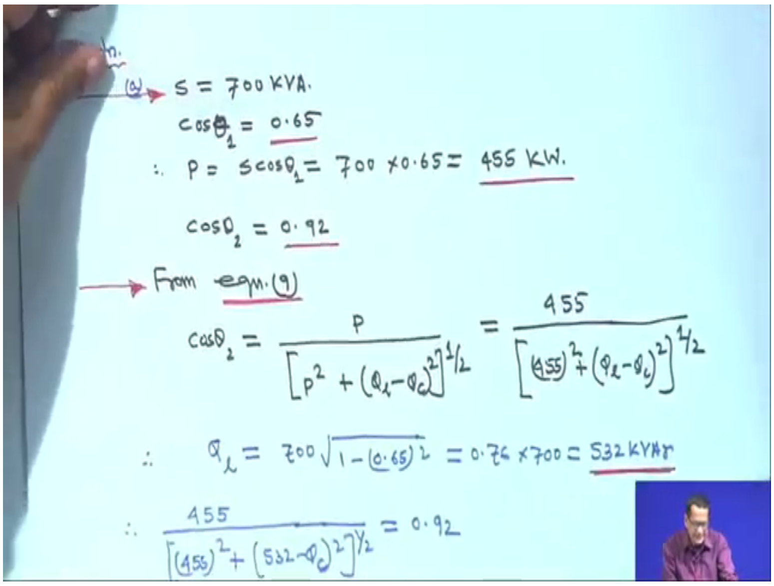

So, in that case S given 700 KVA, it is 700 KVA. Initial power factor is given cos theta 1, 0.65. So, P is equal to your apparent power into cos theta 1. So, a cos theta 1 is equal to 700 in to 0.65 is equal to 455 kilowatt right. So, cos theta 2 is equal to say input power factor is 0.92 from equation 9 we will get cos theta 2 is equal to P upon root over P square plus Q l minus Q c whole square it is putting a half root over.

So, that is actually P is 455 and this is 455 square plus Q l minus Q c square this is half right. So, Q l will be come after because cos theta is your what do you call theta 1 is 0.65. So, substituting all this you will get Q l is equal to 532 kilo hour, this is your this is that this is your load reactive power right this Q l is 532 kilo watt load reactive power now.

Second case what you call this is this is given Q l is equal to given now you put in this equation that your you want to improve power factor to your 0.92. So, cos theta here it is 0.92 P is remains same 455. So, 455 upon 455 square plus 532 minus Q c square to the power half right. So, in that case your what do you call this one that this square it both sides. So, 455 square plus 532 minus Q c square is equal to 455 upon 0.92 whole square.

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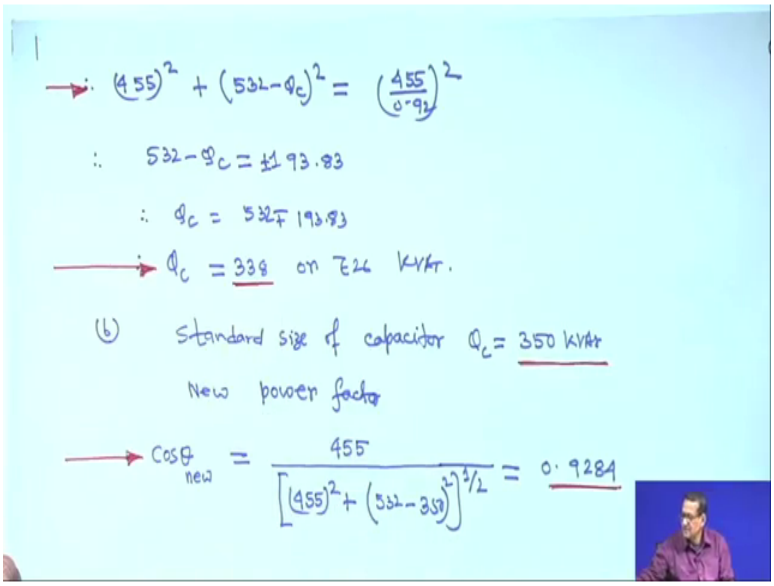

So, it will get 532 minus Q c plus minus 193.83. So, Q c will be just Q c will be just changing the sign 532 minus plus 193.83 or you will have two values Q c will be 338 or Q c will be 726 kilo hour right. But you are what you call your load this Q l is equal to 532 kilo hour right, Q c becomes your what you call 726 it is more than your what you call that will Q l, Q l is 532 or something right.

So, it will apparent reading power factor there is the possibility that will in that case that your receiving an voltage will be higher than the sending an voltage right, but anyway we will take the lower one.

So, that is Q c is equal to 338 kilo watt this is that if point power factor is maintained 0.92 right, but 338 kilo hour capacitor size is not available in the market. So, standard capacitor size maybe Q c is equal to 350 kilo hour it is actually capacitors are available in band like you will 25 kilo hour, 50 kilo hour, and then this is 100 kilo hour, then your 200 kilo hour like that.

So, some combination you have to take a single bank of 350 kilo hour may be available may not be available right, but some combinations. So, standard capacitor will be 350 kilo hour right. In that case new power factor will be same formula same formula that cos theta 2 that equation 9 P upon root over P square plus Q l minus Q c whole square to the power half, but Q l c you should take your 350 instead of you got 338 that is why you got 0.92, but you take your 350.

So, if you take 350 then cos theta nu will be 450 upon 455 square plus 532 minus 350 whole square to the power half, so it is 0.9284. There is slight improvement of the power factor right. So, this is your Q c.

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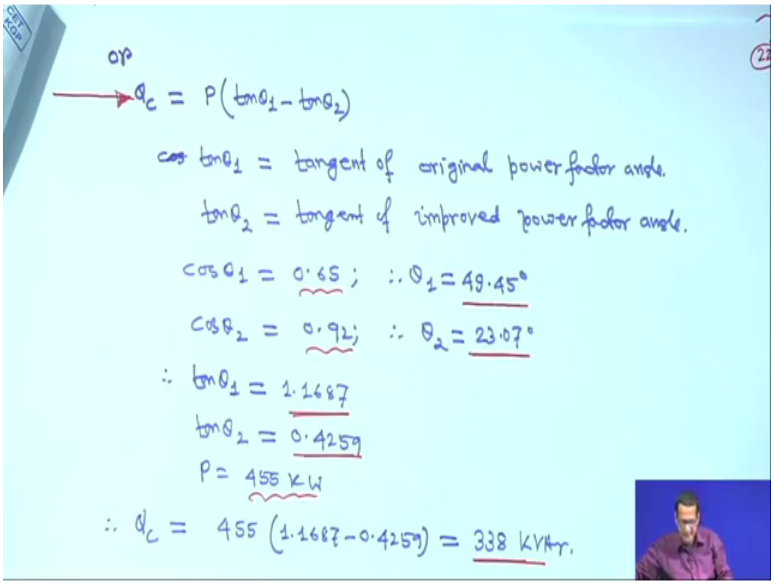

Now, another thing is another formula for computing Q c is equal to P tan theta 1 minus P tan theta 2. Then I have to go to that power triangle right how how we are getting P tan theta 1 minus P tan theta 2. First let me go to that power triangle right whatever we have made it.

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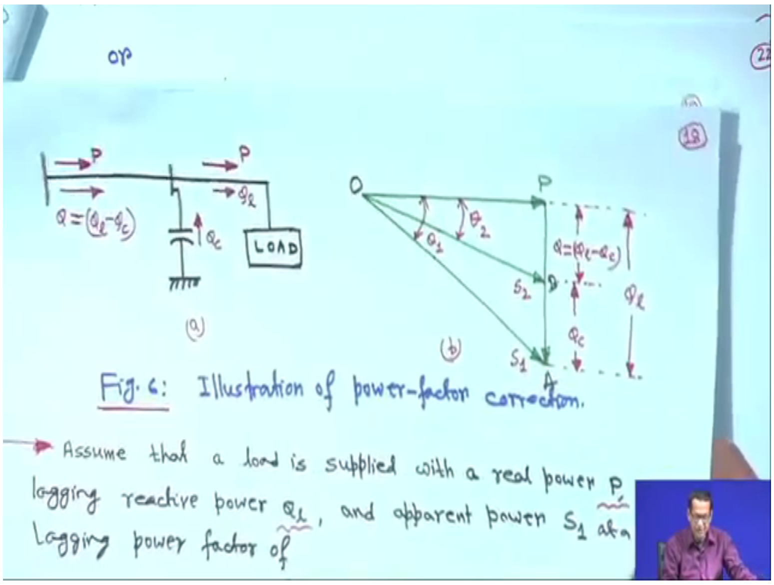

This is your power triangle; this is your power triangle. This Q c you have to make it, this Q c you have to make it, right. So, what will be Q c? Initial power factor was theta 1 right. So, Q is Q c your initial; that means, let me write down here.

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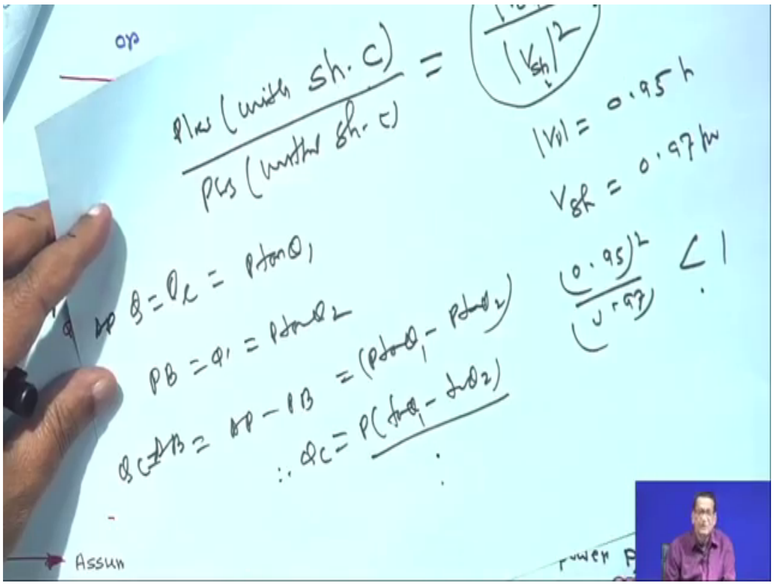

So, initial power factor was theta 1, this theta 1 therefore, say I am making some things your Q, your Q l Q is equal to Q l is equal to P tan theta 1 right. Then new power factor is your theta 2 right; that means, this much you what do you call this P d this your P d, P d, P d this one, P to d this one. So, suppose this is Q is equal to P tan theta 1 and say P b is equal to Q dash that mean this P b Q dash is equal to your P tan theta 2, is equal to P tan theta 2.

But this is actually Q c from here to here that A B actually is equal to Q c in this diagram therefore, A B is equal to your P your this one your AP this is actually your AP this AP minus PB. So, AP is equal to your P tan theta 1 minus P tan theta 2 is equal to P then tan theta 1, theta 1 minus tan theta 2 that is actually this is actually Q c, this is actually Q c.

Therefore this is actually Q c is equal to P tan theta 1 minus P tan theta 2. So, that is why your here in this equation we are writing or Q c is equal to P tan theta 1 minus P tan theta 2 or tan theta Q 1 is equal to that tangent of the original power factor angle.

And tan theta 2 is equal to tangent of improved power factor angle I mean using that other formula also apart from that one, this one also you can use right to cos theta 1 is 0.65, so theta 1 is 49.45 degree. Cos theta 2 is 0.92, so theta 2 is 23.07 degree. So, if you take tan theta 1 that is tan 49.45 degree it is 1.1687 and tan theta 2 is equal to 0.4259.

So, you substitute here P 450 kilowatt that is given. So, Q c is equal to 455 your into tan theta 1 is 1.1687 minus 0.4259 is equal to 338 kilo watt same as you have got earlier also right. So, this is the way that you can calculate Q c, but nearest site is 350 so that is why 350 you have use, but this is another way of computing Q c.

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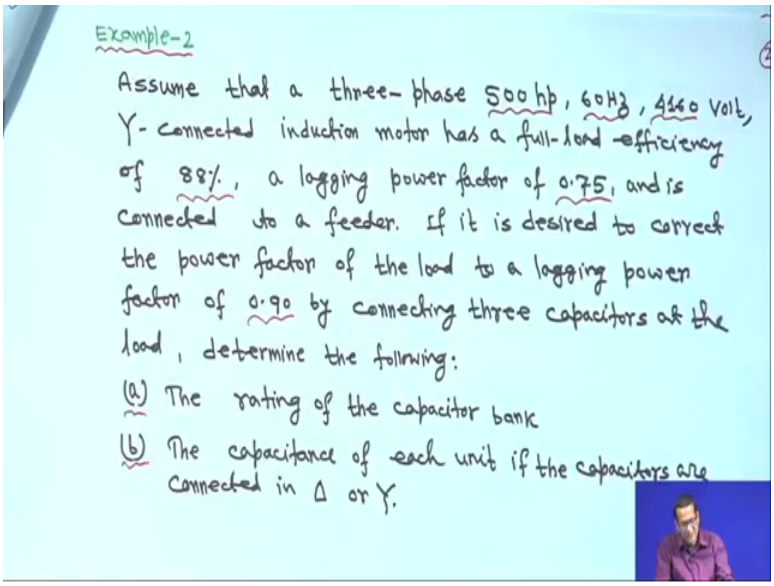

Now, I take another example. Assume that a three-phase 500 horse power h motor operating as 60 hertz and its voltage is 4160 volts that is 4.16 kv right. Star connected induction motor has a full load efficiency of 88 percent 0.88 is efficiency and a lagging power factor 0.75.

So, it is a fore power factor right. And it is connected to a feeder if it is desired to correct the power factor of the load to a lagging power factor of 0.9 by connecting 3 capacitors at the load right determine the following. The rating of the capacitor bank, the capacitance of each unit if the capacitors are connected either in delta or in star right these are the two things you have to do it.

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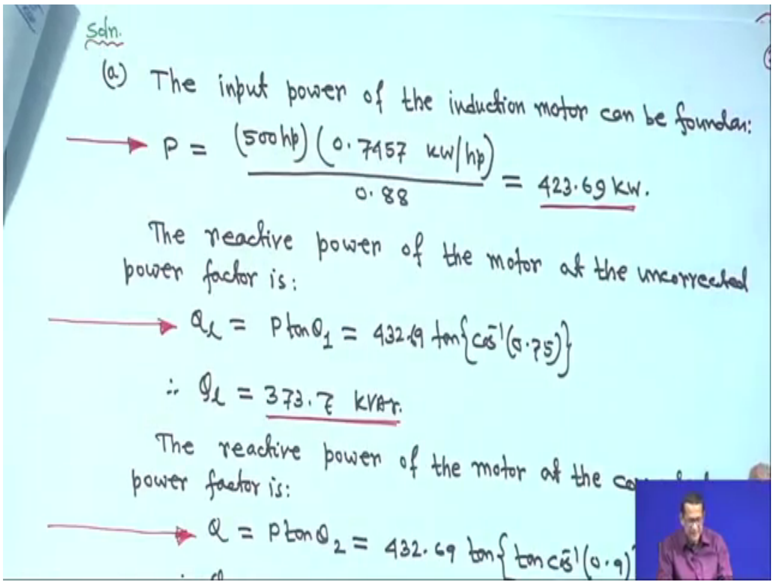

So, first is the induction motor of the your what do you call input power of the induction motor efficiency is given 0.88 and one horse power is equal to 0.7457 kilo watt. So, how I writing P is equal to 500 horsepower and it is 7 power 0.71 horsepower is equal to 0.7457 kilowatt. So, I writing 0.7457 kilowatt per horse power divided by efficiency 0.88 that actually 423.69 kilo hours right.

So, the reactive power of the motor at the uncorrected power factor; just now we have seen that Q is equal to Q l is equal to P tan theta 1 right. So, it is equal to 732.69 cos theta is equal to given cos theta 1 is equal to given 0.75 therefore, theta 1 is equal to cos inverse 0.75 directly you are writing it is under stable understandable to you, so cos inverse actually tan of cos inverse 0.75, right, so this is actually coming 373.7 kilowatt hour that is Q l.

Now, the reactive power of the motor at the corrected power factor now corrected power factor is 0.9, so cos theta 2.9 there for your theta 2 is equal to cos inverse 0.9. So, that is why this your what you call twice I have written tan it is actually 432.69 tan of your cos inverse 0.9 right, whatever angle it comes.

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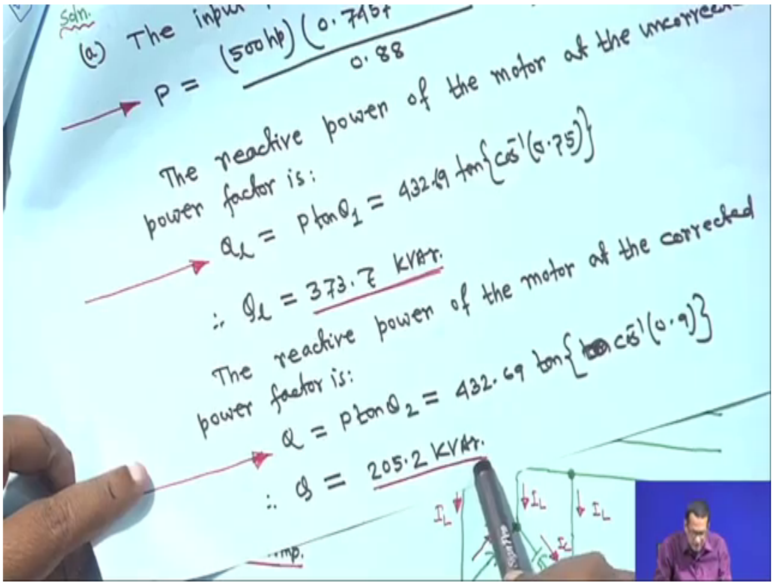

So, Q will become 205.2 kilo hertz this is your second case. Then what is the Q c? Then you have to subtract that one what will the value of Q c right. So, this is your total Q and this is your after power factor improvement. So, subtract this one from this one that will give you Q c value.

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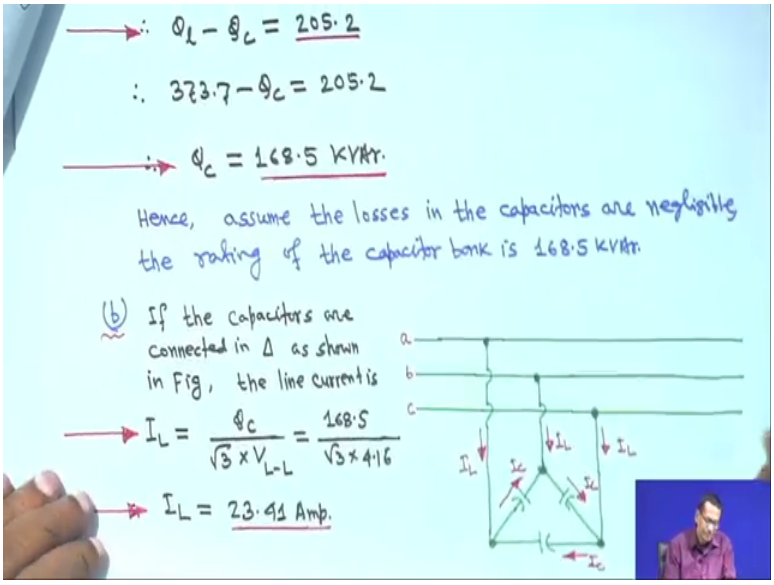

So, in that case that is your Q l minus Q c that is your Q c; that means, your this is Q l minus Q c. So, this is whatever you have got Q l minus Q c. So, Q l minus Q c is equal to 205.2. So, Q c is equal to your this one minus this one same thing right. You subtract this one from this one right. So, you will get Q c is equal to 168.5 kilo hour this is the capacitor you require.

Now, hence assume the losses in the capacitors are negligible suppose there is no loss in the capacitor therefore; the rating of the capacitor bank will be 168.5 kilo hour. Now, if the capacitors that it is given you find out the value of capacitance c if the capacitor either it is delta connected or it is star connected right. So, this is the 3 phase line abc phase right. So, you we are taking the capacitors are delta connected. So, this is I C, I C, I C the capacitive current and this is the line current I L, I L balance system. So, all are same right.

So, figure number I have not given here if the capacitors are connected in dell tan shown in figure actually this is the figure know number is required here it is numerical. So, this is the figure right. So, you know that is three-phase one. So, your root 3 V line to line voltage into I L the load current is equal to Q c therefore, I L is equal to Q c upon root 3 into V line to line voltage you are writing directly.

So, Q c is equal to it is 168.5 and line to like voltage it is root 3 into V it is line to line voltage is given in the numerical that is your this value for that is 4160 voltage that is your 4160 volt. So, it is actually 4.16 kv divided by 1000 right. So, because Q c is we are taking at a kilowatt. So, voltage we are taking actually kilovolt. So, maturely I will be in terms of it will be in current ampere right 23.41 ampere. This is the your what do you call load current right and it is a balance system the magnitude of the current.

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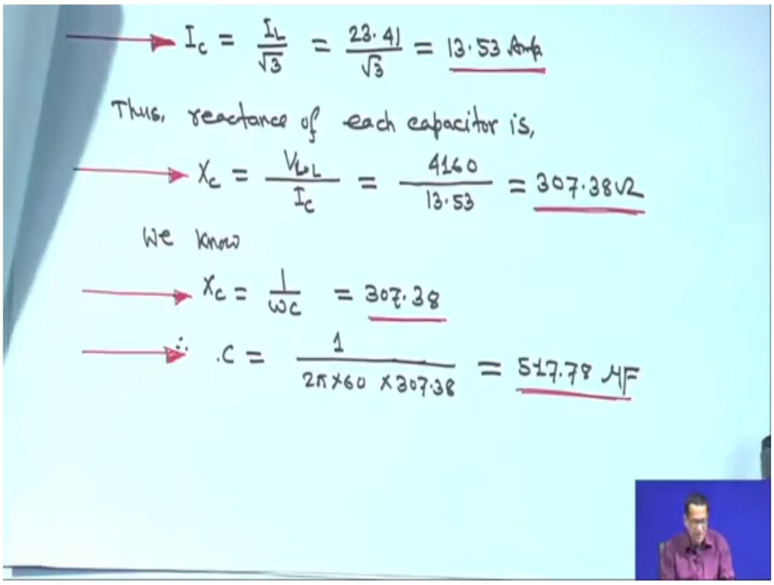

Now, therefore, that I C is equal to I L by root 3 because these are load current and these are delta connection. So, your phase current will be your what do you call line current by root 3 right; that means, I C will be I L upon root 3. So, in that case I C equals is equal to I L upon root 3.

So, that is your 23.41 upon root 3 that is 13.53 ampere that is I C right; that means, which is the current flowing through the capacitor this is the current right. Therefore, X c is the reactance of each capacitor we can write X c is equal to you can write V L L upon I C right. So, in that case whatever value you will get right, so this is a delta connection, so why line to line voltage this point means this point this point mean this point.

So, line to line voltage actually impress that is how the capacitor, because this point this point same this point this point same. So, just take one example. So, that the line to line voltage is impress across the capacitor that is why you are taking X is equal to V line to line upon I C.

So, that is actually without we have putting I C is ampere we are putting this one as a volt then we will get the ohm, so 4160 instead of k V 4160 volt by 13.53 ampere. So, it is coming 3.7.38 ohm right. And we know that X is equal to magnitude of course, one upon omega C and this one is equal to 307.38 if you solve this one omega is equal to F is 60 hertz, so 2 pi a and C is equal to 1 upon omega into X C. So, 307.38 you will get 517.78 microfarad the C value; that means, this capacitance value is two microfarad right.

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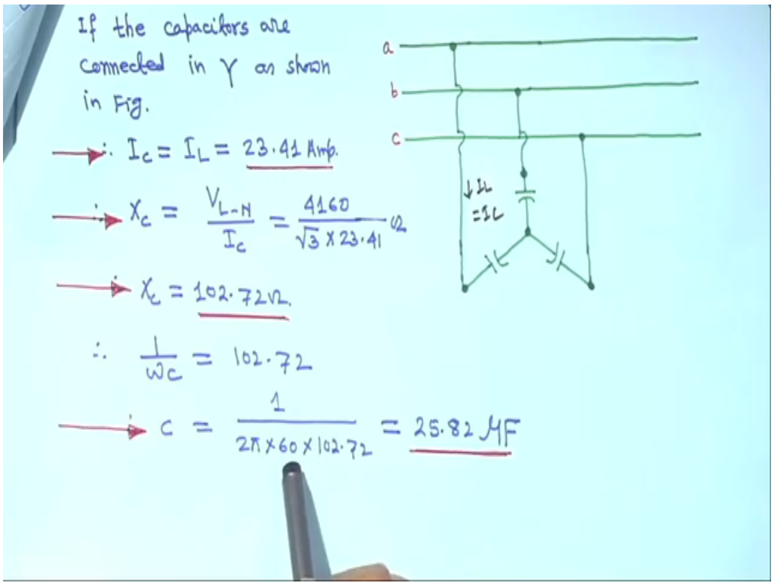

So, now if it is a star connected then I L is equal to I C, if it is star connected one I am showing in every phase that I L is equal to I C, I forgot to mention it here that is why I write here I L is equal to I C it is a star connected right. So, in that case if the capacitors are star connected then I C is equal to I L is equal to 23.41 ampere right. In that case your you have to take the line to new line to line voltage because it is a star connected right.

So, in that case it will be your V line to neutral is equal to 4160 by root 3 and I C is equal to 23.41 ampere right. So, x you will get 102.72 am ohm. So, again x is equal to 1 upon omega C is 102.72 and it is 60 hours system, so C will become 25.82 microfarad right. So, this is that problem.

So, it is not difficult one easy one, but if it is star connector and if it is delta connected whatever it is that bar has to be saved right. Capacitance value different, but rating has to be same and it is your yours choice, so either you go for a delta or star connection. But let me tell you one thing there question to you whether under such conditions whether will pay for delta connection or star connection of this capacitor I have if I have taken delta and star both, but this is a question to you delta or star please I mean when you will listen to this video please you tell me the reason in writing few points right which one you will prefer. And which one will be better either delta or star right. Think and then you will answer do not do not try to write quickly, you have to think and you have to answer right.

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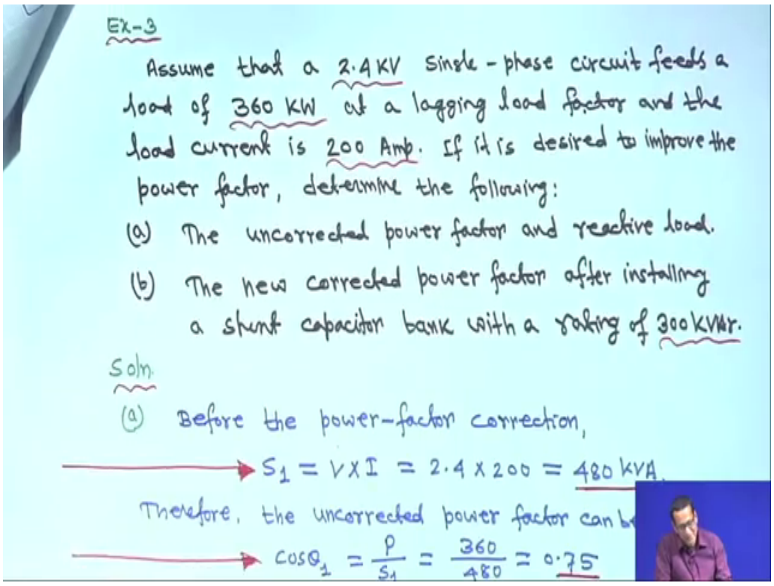

Now, example 3 assume that a 2.4 kilo volt single phase circuit feeds a load of 360 kilowatt and lagging power and at a lagging load power factor and the load current is 200 ampere right if it is desired to improve the power factor determine the following right.

So, the uncorrected power factor and reactive load; The new corrected power factor after installing a shunt capacitor bank with a rating of 300 kilowatt. This 300 kilowatt you have shunt capacitor bank in main shed. So, you have to find out all these right. So, in this case the solution for a right; before the power factor correction right that S 1 is equal to V into I, the apparent power V I you know as this thing.

So, 2.4 kv is the voltage and current is two hundred ampere. So, it will become 48 KVA right. So, therefore, the uncorrected power factor cos theta will be P upon S 1 this P actually give 360 kilowatt this is given this is given therefore, it is 360 upon 480, so 0.75 right power factor 4 power factor 0.75, right.

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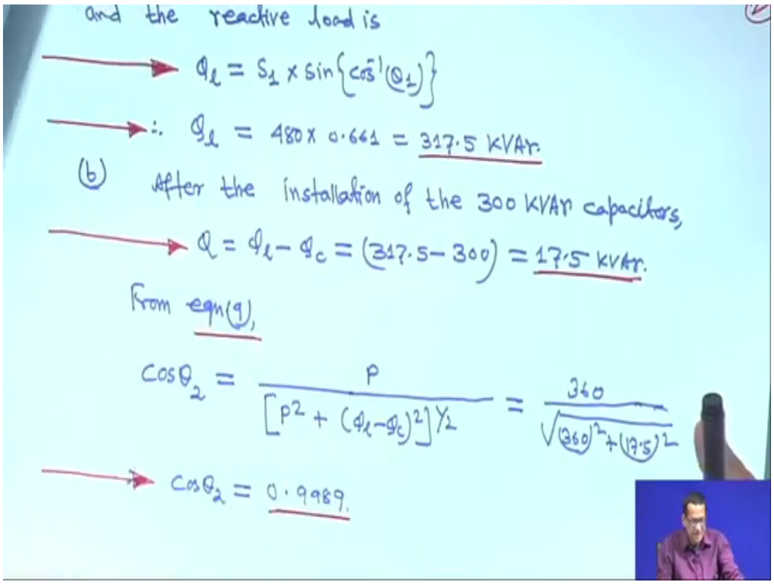

So, now and the reactive load is that S 1 is equal to that cos theta 1 is 0.75. So, theta 1 is cos inverse theta 1. So, you can calculate easily at instead of calculating directly I am writing S 1 into sin of cos inverse theta 1 right. So, Q l is equal to S 1 is 480 and this part will be 0.661 that is 317.5 kilowatt that is your reactive load demanded at the your load right.

Now, after the installation of 300 kilo hour capacitor effective Q will be Q l minus Q c, so 307.5 minus 300. So, it will just 17.5 kilo hour. So, from equation 9 you know that cos theta 2 the new power factor right, after placing the shunt capacitor that P is equal to P square plus Q l minus Q c whole square to the power half right. So, that is P is equal to 360 divided by 360 square and this is Q l minus Q c 17.5 square. So, power factor is nearly unity 0.9989 cos theta 2, right.

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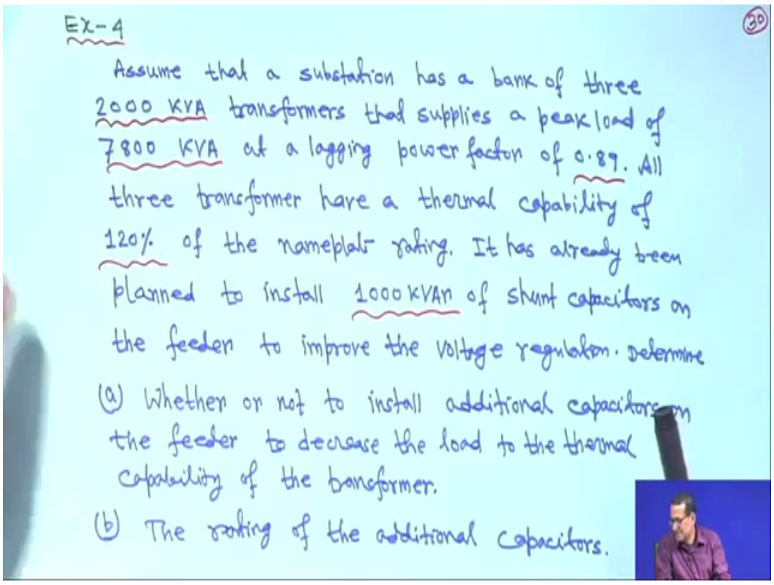

So, next one is an another example right. So, assume that a substation has a bank of three 2000 KVA transformer right, and your the that supplies a peak load of 7800 your what you call KVA right; So, at lagging power factor of 0.89. So, it is a good power factor.

All 3 transformers have a thermal capability of 120 percent of the nameplate rating capacitor, that is that whenever the gain this kind of thing that 120 percent of the thermal rating thermal capability; that means, you will concentrate this way that I am sure that you have studied in machine design also for transformer design the meaning is you take it other way this transformer can take overload of 20 percent more than that right.

So, when it language will be something like this the thermal capability 120 it thinks about from the temperature raise point of view and a installation failure also right.

So that means, the temper the transformer can take a maximum of 125; 120 percent of the over load that is how that is the meaning. It has already been planned to install 1000 kilo hour of shunt capacitors on the feeder to improve the voltage regulation; that means, that your what you call that V s minus V r will improve; that means, you are trying to improve the transformer voltage your regulation I can say that you know that whatever voltage regulation I have studied for the transformer, right.

So, determine a whether or not to install the additional capacitors on the feeder to decrease the load to the thermal capability of the transformer or the rating of the additional capacitor right.

But whether or not to install additional capacitor on the feeder, whether there additional capacitor will installed to the feeder such that to decrees the load to the thermal capability of the transformer this is the meaning and the rating of the additional capacitor, if so, then what will be the rating of the additional your capacitor right.

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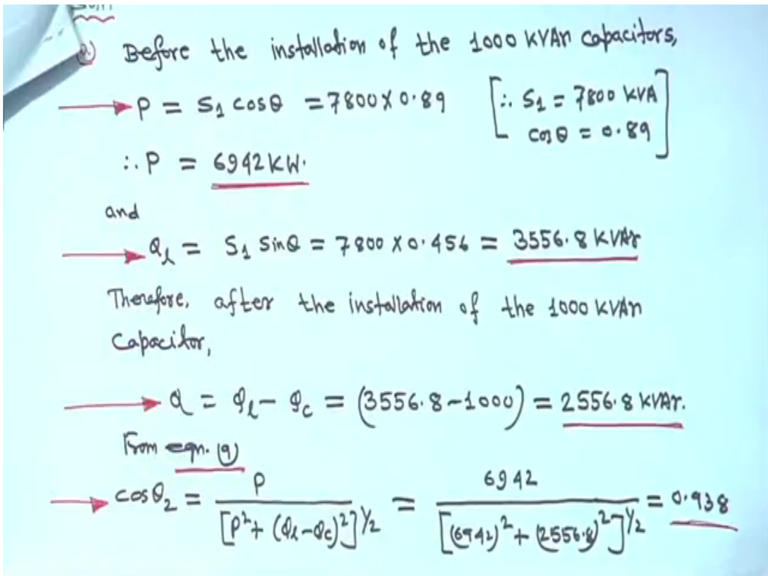

So, in this case, so before the installation of the 1000 kilo hour capacitors P is equal to S 1 cos theta it is given 7800 KVA into 0.89 it is given here and I have written here P is equal to 6942 kilowatt. Therefore Q l will be S 1 sin theta, so cos theta is 0.89. So, sin theta will become 0.456, so 7800 into 0.456 it is 3556.8 kilohertz.

Therefore, after the installation of the 1000 kilo hour capacitor Q will be Q l minus Q c. So, this is your Q l this much of the reactive load reactive power required in the load. So, Q should be is equal to Q l minus Q c that is your this much minus 1000 it is 2556.8 kilo hour right.

From equation 9, from equation 9 we know that cos theta is equal to P upon P square plus Q l minus Q c whole square power half. So, P is given 6942, this 6942 upon 6942 square and Q l minus Q c is 2556.8. So, 2556.8 square to the power half, so 0.938. So, power factor in the second case initial is 0.89 now power factor is improved because of this 1000 kilo hour capacitor this power factor is improved, right.

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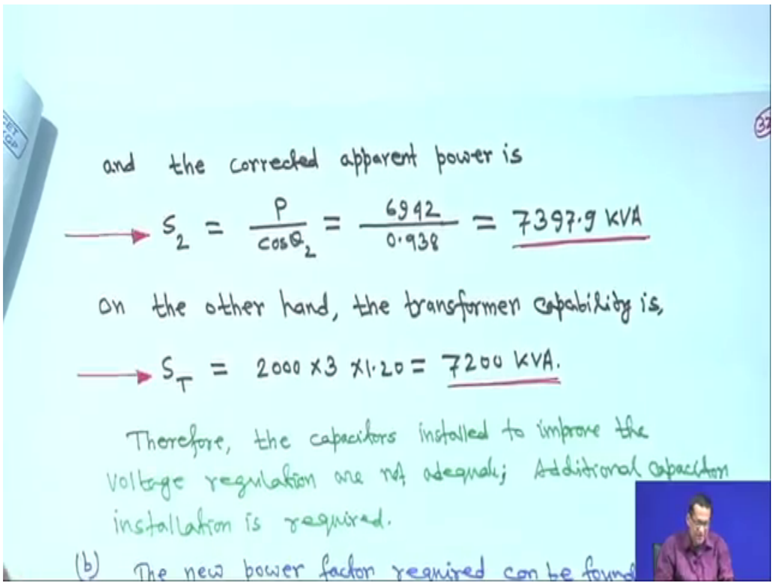

So, therefore, and that corrected apparent power is S 2 is equal to P upon cos theta 2 there for 6942 upon 0.938, so 7397.9 KVA right. So that means, corrected apparent power is 7397.97 KVA therefore, on the other hand the transformer capability is because there are three 2000 KVA transformer, so it actually 2000 into 3 in the power loading capability is 1.2, so it is 7200 KVA right.

But here it is 7397.9 KVA therefore, the capacitor installed to improve the voltage regulation, are not adequate, right because this is less than this one therefore, additional capacitor installation is required.

Thank you. We will meet.