Power System Engineering
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Lecture –43
Application of capacitors in distribution system (Contd.)

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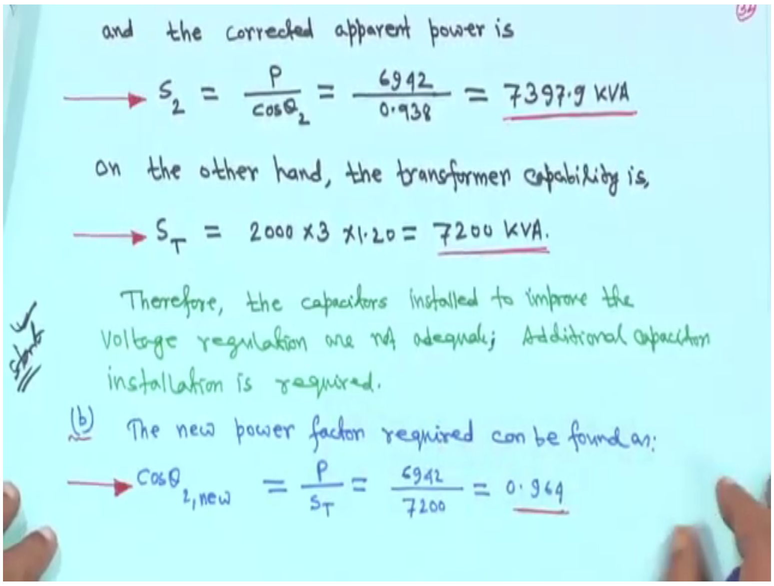

Ok so, we have seen that this S2 value is 7397.9 kVA; that means, 7 roughly 7398 kVA and here that are transformer capabilities 7200 kVA. Therefore, the capacitor installed, to improve the voltage regulation are not adequate.

Therefore, additional your capacitor is required. Now, in the second case the new power factor require can be found as that cos theta 2 new right is equal to P upon S T; P we know 6942 kilowatt and S T is 7200 kVA. Therefore, it is 0.964 right? So, new power factor.

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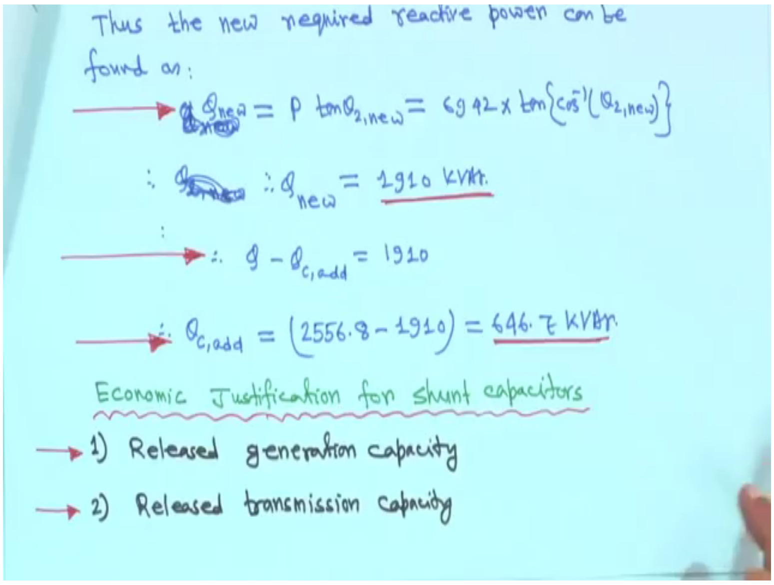

Now, thus the new required reactive power can be found as that Q new; this is actually Q new is equal to P tan theta 2 new. So, that is 69P is 6942 into tan and cos it is inverse theta 2 new right; that means, cos theta 2 new you have got it 0.964. So, theta 2 new is cos inverse what whatever. You put these values here right. You will get Q new is equal to1910 kilowatt right.

Therefore, we know Q new is equal to Q minus Q c; it is add means additional capacitor that is Q c add is equal to1910. Therefore, Q c add is equal to Q is equal to 2556.8 and minus the here 1910. So, it is coming see 646.7 kilowatt; that means this amount of additional amount of power required right.

Now, this economic justification for shunt capacitor; now, I will tell you this but when all these things will be completed. I will explain each and every thing later but first is that economic justification; first is it release generation capacity. What does it mean? I will come later; release transmission capacity that also I will tell you right.

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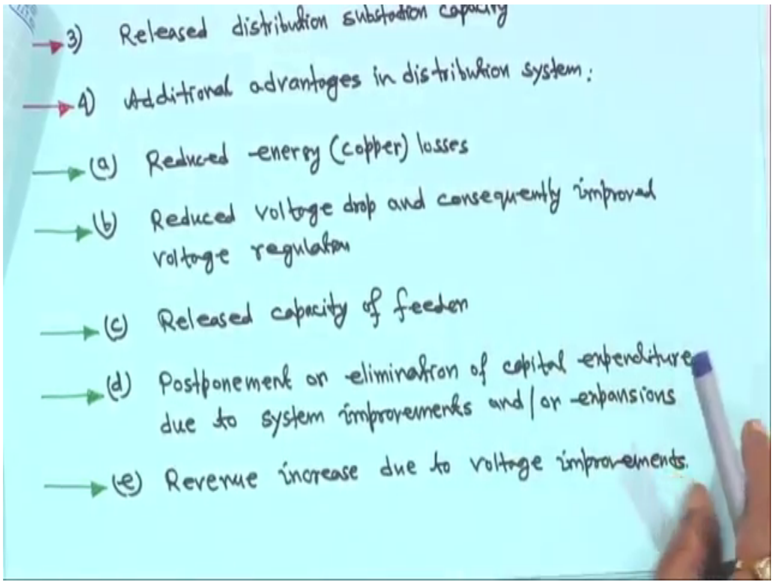

Then release distribution substation capacity, then number 4 additional advantages in distribution system a, b, c, d, e, f four six things are there. One is reduce energy that is I square r loss it will reduce; reduce voltage drop and consequently improve voltage regulation. This is also because of the shunt capacitors effect; release capacity of feeder because it will draw that because of shunt capacitor that feeder will draw less amount of current we will come to that also. Although something I have explained on this.

Then postponement or elimination of capital expenditure due to system improvements error and, or expansion. I think this is happening because of the distribution substation capacity release right and if you put capacitor then feeder may not be overloaded.

So, that your what you call expansion or your what you call that your of the distribution system or improvements you can differ by few years. Then revenue increase due to voltage improvement. If voltage in improves then naturally energy meter reading will be higher right.

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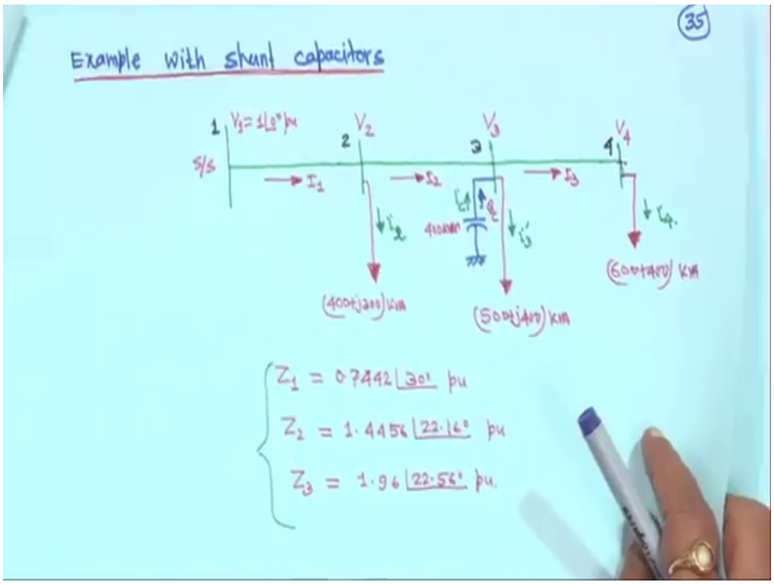

Because it will that is the thing right and another this these a, b, c, d the actually this five your what you call advantages for under distribution system; other three regarding the generation and transmission site but when I will come to the end all this point I will take and I will explain how is it right.

Now, example with shunt capacitors right; for example, suppose we take the same data we take the same data same 4 bus example. This is bus 1, bus 2, bus 3, bus 4; voltage is here substation; this is slag bus; this is 1 angle 0; V2, V3, V4. Suppose we have connected a shunt capacitor at node 3 right.

So, you although here for the calculation this I c actually is not require, but still I have showing that Q c being injected and corresponding current is I c and this capacitor value; say we have taken 400 kilowatt right. Therefore, and this loads are already given this is 400 plus j 300 kVA; this is 500 plus j 400 kVA and this is 600 plus your j; I have missed here it is j 400 kVA right.

That is 400 kilowatt, 300 kilowatt, 500 kilowatt, 400 kilowatt, 600 kilowatt and 400 kilowatt and when you put a two thing in bracket they are in kVA and this impedance is also same. It is in per unit right Z 1 is 0.7442 angle 30 degree per unit Z 2 is equal to 1.4 456 angle 22.16 degree per unit and Z 3 is equal to 1.96 angle 22.56 degree per same impedance and a capacitor is connected.

Now, if you have connected a capacitor here; there is capacitor injecting power. Then what will be the effective load here? It will be 500 plus j 400 minus 400; that means, here it will be 500 plus j 0 because this is this till kilowatt part is been compensated by this shunt capacitor right. So, if you for your understanding what I have done I have made another equivalent diagram of this one. So, in that case this is substation again everything is same, but here at node 3; that this capacitor is connected.

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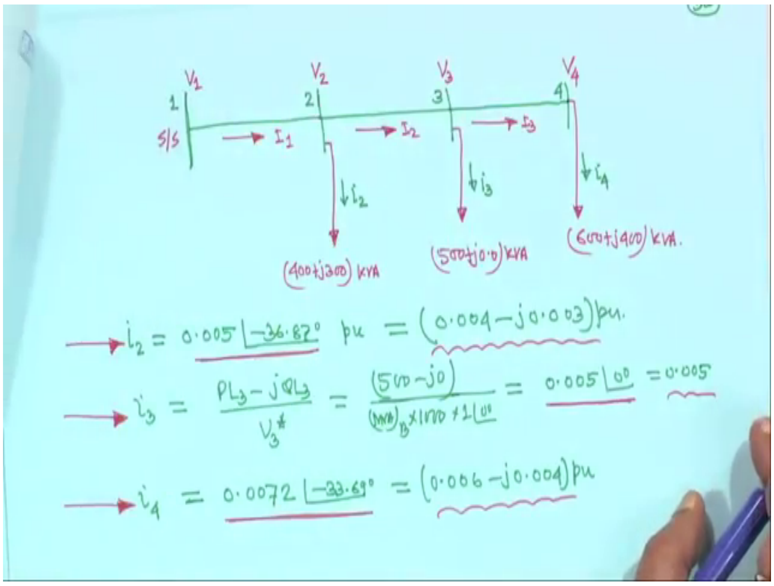

Therefore, it is 500 plus j 0 because this one is totally compensated by this one right. So, in that in that case your and work for this one what we will do? We will use only the first method of the load flow. Second method I have not done it here, but I request you can check also using the second method.

So, then you compute the current for i 2. It will be voltage plus voltage start; that means, all the voltages initial values are taken 1.

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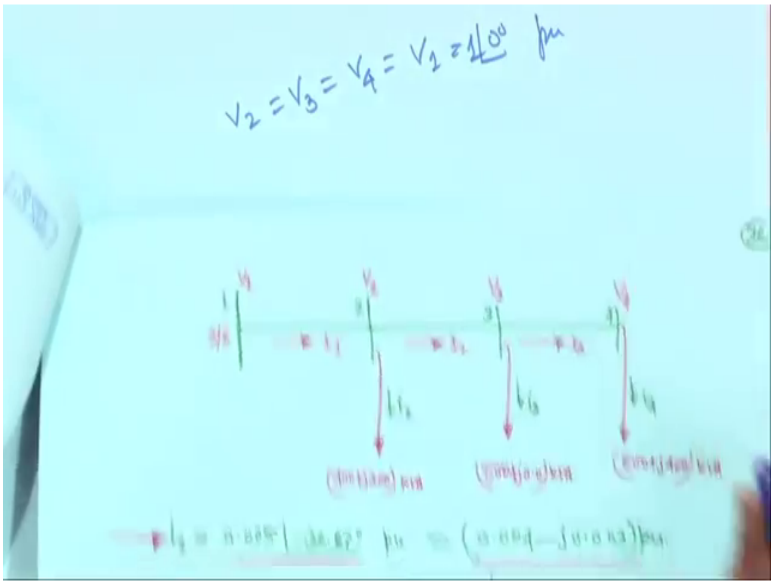

That is V 2 is equal to V 3 is equal to V 4 is equal to V 1 is equal to1angle 0 degree per unit right. So, all the all the all the node voltages V 2 , V 3 , V 4 are taken as the you know slag was voltage. So, slag voltage start and so, in this case this i 2 , i 3 , i 4 , i 2 in i 2 we have initially calculated. It is p 2 minus your p l 2 minus j Q l 2 upon your V 2 conjugate, but all the initial values are1 angle 0. So, this is actually your i 2 is equal to 0.005 angle minus 3 6.87 per unit. So, that is 0.00 4 minus j 0.00 3 per unit.

Now, i 3 in the case i 3 now, it is actually p l 3 minus j Q l 3 upon V 3 conjugate actually effectively Q l 3 here is 0; this is equivalent diagram. So, Q l 3 is not there. So, basically it is 500 divide this is a these are been converted to per unit divided by your 500 k kilowatt divided by 1000; it will be megawatt divided by MVA base. So, basically 500 by 10 to the power 5 into 1 angle 0 because it is 1 angle 0 this V 3 conjugate or V 3 same because angle is 0 right. So, it if you compute it will become just 0.005 angle 0 degree that is 0.005 real values for this case.

And i 4 is equal to same as V 4. So, it will be you this you convert it to per unit divide by 1000; it will become megawatt; then they were divide by MVA base same as V 4 and similarly you will get i 4 is equal to. This already we have calculated when you are solving that load flow right; same data, I have taken same data thought out this chapter. So, i 4 is equal to 0.0072 angle minus 33.69 degree that is 0.006 minus j 0.004 per unit right; this is i 4. Next what you have to do is you calculate the branch current that is i 1 i 2, i 3; i 1 will be is equal to your i 2 plus i 3 plus i 4; the small i 2 small i 3 plus small i 4.

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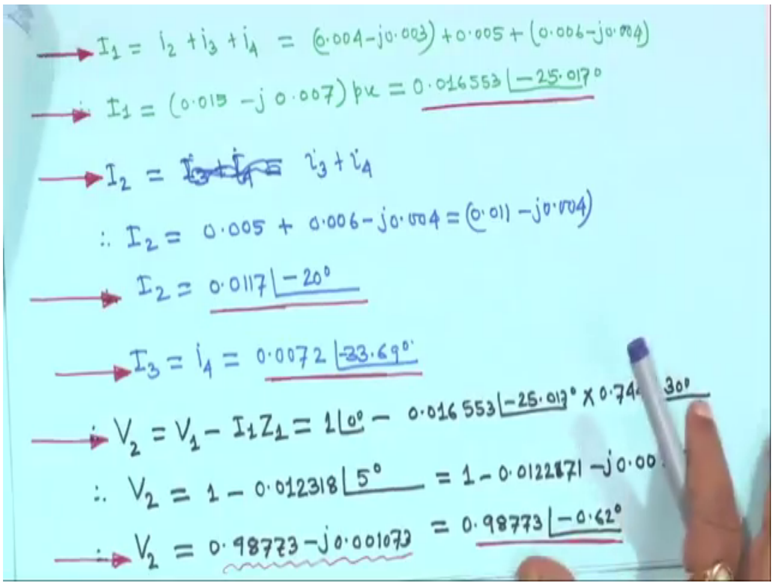

So, I 1 is equal to I 2 plus I 3 plus I 4 this small I small i’s right. So, you add it is this is your I 2; this is your I 3 and this is your I 4. So, if you add it will become 0.015 minus 0.007 per unit and its magnitude will be 0.16553 angle minus 25.017 degree. Similarly I 2 is equal to I 3 plus I 4; I 2 is equal to I 3 plus I 4 right. So, I 2 is equal to your I 3 is this much and I 4 or what do you call I 3 is your this much 0.005 and I 4 is this much. So, it is coming actually 0.011 minus j 0.004; that is I 2 is equal to 0.0117 angle minus 20 degree.

So, and I capital I 3 is equal to I 4 because this is a last node I 3 is equal to I 4. So, this is a last node. So, I 3 capital I 3 is equal to small i 4 that is 0.0072 minus 33.69 degree right. After this all the branch currents are computed. This is first iteration; I am not writing any iteration number here. When second iteration will come I will do that but these are all first iteration right. Then V 2 is equal to then V 1 minus i 1 Z 1. Substitute V 2 with V 1 value, then I 1 value then your Z 1; Z 1, Z 2, z 3 all same value same value all in per unit. So, it is actually coming V 2 is equal to 1 minus 0.012 318 angle5 degree.

So, if you multiply and simplify all these things; V 2 actually coming 0.98773 minus j 0.0001073; so, this is actually 0.98773. So, angle minus 0.62 degree. This is V 2 in the first iteration only right. So, similarly V 3 will be V 2 minus your I 2 Z 2.

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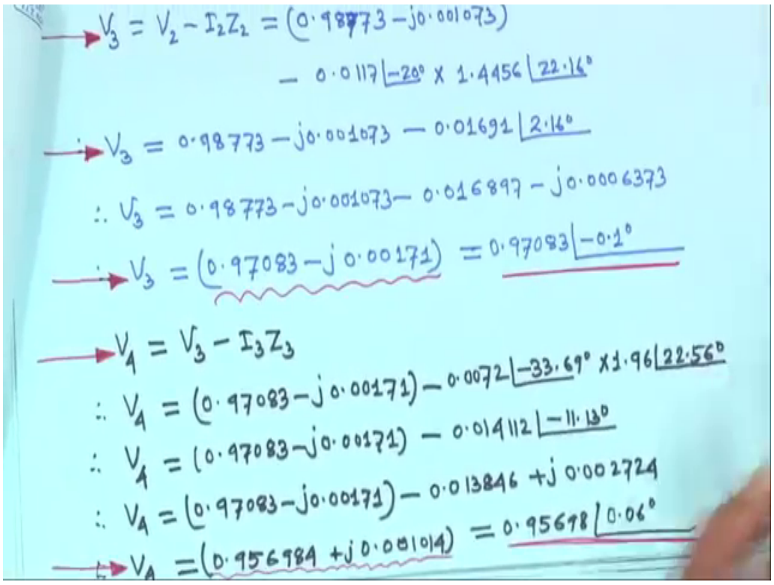

So, similarly V 3 is equal to V 2 minus I 2 Z 2 right. So, it is 0.98773 that is V 2 minus j 0.001073, I mean this V 2; these V 2; these V 2 right. So, minus your I 2; this is I 2 and this is Z 2. All this things are known. So, just simplify right. So, you will get basically after simplification all this things you will get V 3 is equal to 0.97083 minus j 0.00171.

So, this is magnitude is 0.97083, but angle is minus 0.1 degree. Look here because of the capacitor earlier when capacitors was not there all though this angle is very small, but it was coming leading angle, but as soon as you have put the capacitor; look this angle is a change, it is a lagging angle now all though it is small, but it is lagging angle.

Similarly, here also V 3 if you look it is minus 0.1 degree, but it is your what you call it is lagging angle right and if you talk of a compute V 4; V 4 is equal to V 3 minus I 3 Z 3. So, V 3 is this one; V 3 is this one; minus your I 3 is this one and this is your Z 3. So, multiply and simplify all this things then what you will get V 4 is equal to 0.95698 plus j 0.001014; it comes around 0.95698 angle 0.06 degree.

Here, it is leading angle but very small, but leading angle. But other two is your is coming lagging angle right. So, all this calculations whatever I made by calculator I request you when you will go through this lecture note, read your lecture anything, you have please verify whether I am right or wrong. If you find any mistake in calculation you just please let me know.

Now, question is that that last voltage angle it has become actually here in this first your what you call after first iteration, this voltage angle become positive because this is 0.06 degree, but here these two are becoming your negative; I mean lagging this thing right.

So, in the explanation I told you something, but it does not mean depends of course on the capacitor value but I told you that wherever you connect the capacitor; shunt capacitor from that point to the to the source right, it will be affected only this; affected means that loss reduction will occur only in this these branch and these branch for this example right.

And whatever your what you call that voltage drop or your minimal your that whatever current it was drawing without capacitor and because of this capacitor this branch and this branch current will be less but here I 3 will remain more or same because as it is connected at node 3. So, beyond this node any nodes are there it will not be affected.

Whatever little bit because of this capacitor this voltage this voltage will improved because of the improvement this voltage also to some extent will improved right, but your power loss at this branch, reduction will be just only due to this voltage improvement, but that magnitude will be very less. But here your first thing is that current will reduce because if we take I 2 is equal to I d your what in this diagram previous diagram.

Suppose in this case if current is say branch 2 say I d 2 plus minus j I Q 2 and this I c is injecting. So, your imaginary component of the current or reactive component of the current will decrease. Therefore, voltage drop will be less. So, voltage will automatically improve.

Here also it will decrease, but this I 1 is higher than this one for this example say; that means, the reactive component of this one is higher than this one but as soon as this I c is coming here also, it will be subtracted from the reactive component of the current but whatever reduction part here will be much more compared to this one because this reactive part is higher than this part. So, loss reduction also will be here, but it compared to if you take the same resistive values.

Then compared to this one it will be it will be here reduction will more; here reduction will be less. If you assume same r right, but anyway it depends on the your resistance as well as the reactance of the branch right. So, so this is your what you call that V 2, V 3 and V 4 and this is your after first iteration after first iteration; So, next if you move to the second iteration.

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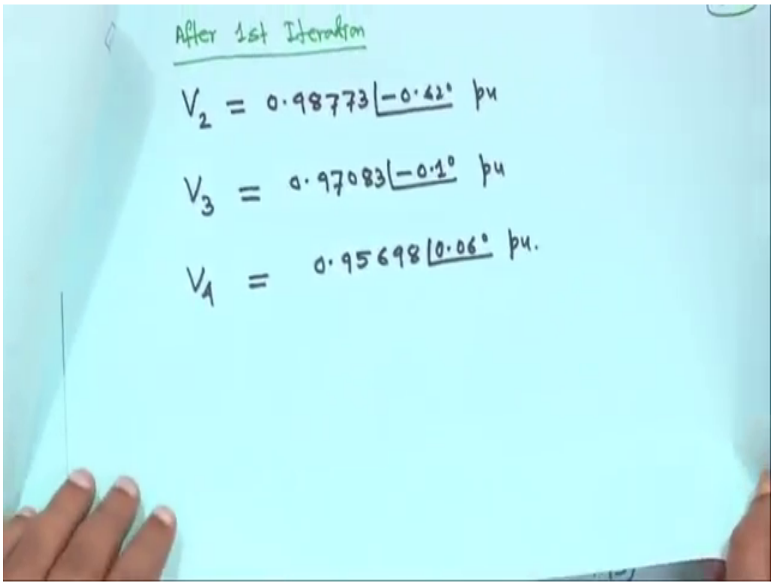

So, after first iteration these are the voltages; V 2 is given whatever we have got it V 3 is given and V 4 is given. This two are lagging angle; although angle is very small and negligible, but and this one is leading angle.

Now, second iteration we will now seeing second iteration we have to compute the your what you call that load current small i 2, small i 3 and small i 4.

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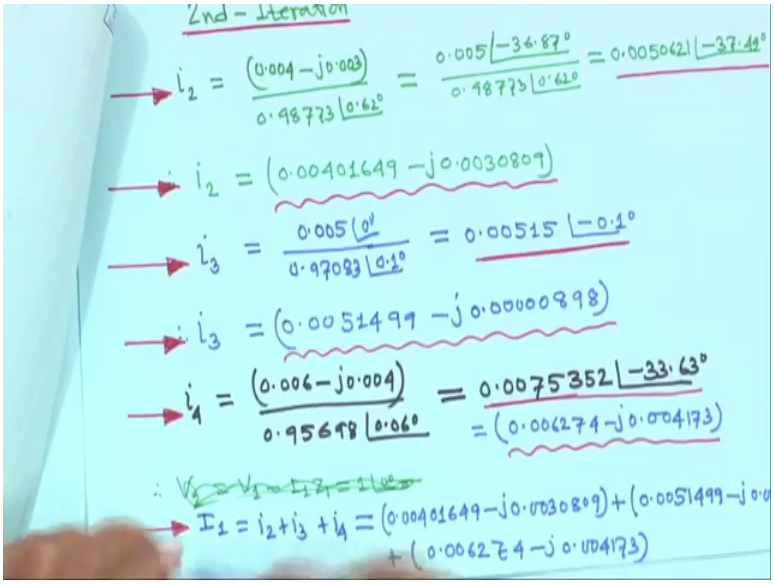

So, second iteration this small i 2 will be 0.004; this is the load P l 2 minus j Q l 2 upon that V 2 conjugate right. So, it is V 2 is equal to 0.98773 angle minus 0.62; its conjugate will be this angle will be plus right. So, it will be 0.98773 angle 0.62 degree. If you simplify if you just simplify then i 2 will become 0.005062 an angle minus 37.49 degree. So, if you just is equal to it is i 2 is equal to 0.004 01649 minus j 0.0030809.

Similarly i 3; i 3 is now only P l because Q l has been compensated. So, this one divided by your V 3 conjugate. So, V V 3 we have got it 0.9708 angle where minus 0.1. So, it is conjugate; it will be 0.1 and you simplify it will become 0.00515 angle minus 0.1 degree because there is nothing means it is angle is 0 because here you have known reactive parts. So, its angle is 0 right. So, it will be minus 0.1 degree.

Now if you simplify this part is negligible actually it is five naught 898 because of this one. So, real part is dominating right. So, i 3 is equal to 0.051499 minus this j 0.5 naught 898; this is actually you can neglect right, it has no effect. So, i 4 is equal to now your P l 4 minus j Q l 4 upon your V 4 conjugate. So, in that case your what you call this one this one i 4 previous for just hold on previous page; i 4 is equal to V 4 conjugate it is minus actually; it is minus right. It is conjugate means it is minus right.

So, you are if you just make this your what you call this calculation or your i 4 is equal to; so, it will be coming your 0.0075352 minus 33.6. This, although this is a by mistake it is written minus but I think this angle is taken correctly right. So, in this case so, this one is equal to it is 0.006274 minus j 0.004173 right. So, with this now your what you call that capital I 1 is equal to i 2 plus i 3 plus i 4; sum up all the currents right. Then you will get the second iteration the branch current. This is your, this is your second iteration second iteration right.

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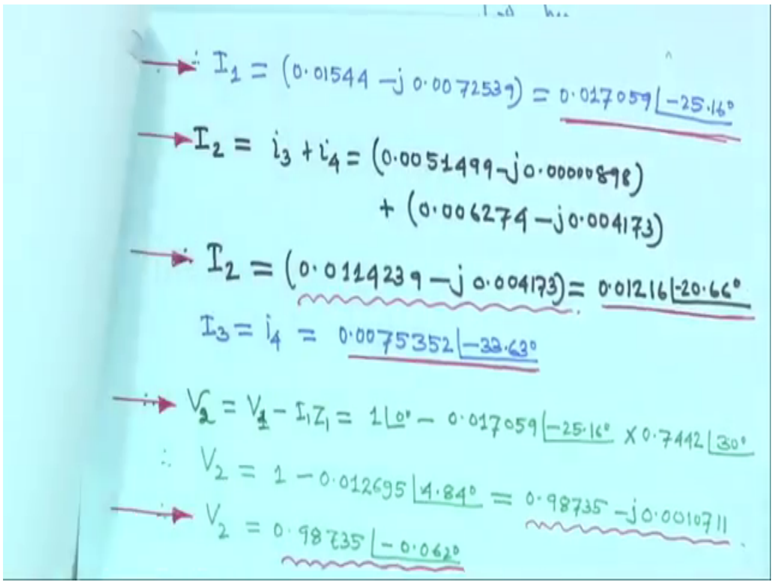

With this you will get I 1 is equal to after simplification you will get 0.017059 angle minus 25.16 degree. So, similarly capital I 2 is equal to small i 3 plus i 4. So, this is your this part actually negligible for i 3 right, but still I have written here plus this one your i 4 right. If you make it simplify and make it; it will become 0.01216 angle minus 20.66 degree.

Similarly capital I 3 is equal to small i 4 is equal to 0.0075352 angle minus 33.63 degree right. So, this is all I 1, I 2, I 3; then I will I will I will suggest you for faster calculations; at least for this example, the voltage angle actually very small. This voltage angle right; all this voltage angles are very small this one this one all this angles are very small. So, even if you even if you neglect this angle directly if you take the voltage magnitude you will get a quicker solution and very close to the actual solution right.

So, now in the second iteration V 2 is equal to V 1 minus I 1 Z 1. So, put as 1 angle 0 everyone and put all this value in the second and in this is this is your Z 1; this is your Z 1 and you simplify. If you simplify, you will get V 2 is equal to 0.98735 angle minus

0.062 degree right, in per this are all per unit. These are all per all calculations even if you have a not written because again and again, but these are all per unit values right.

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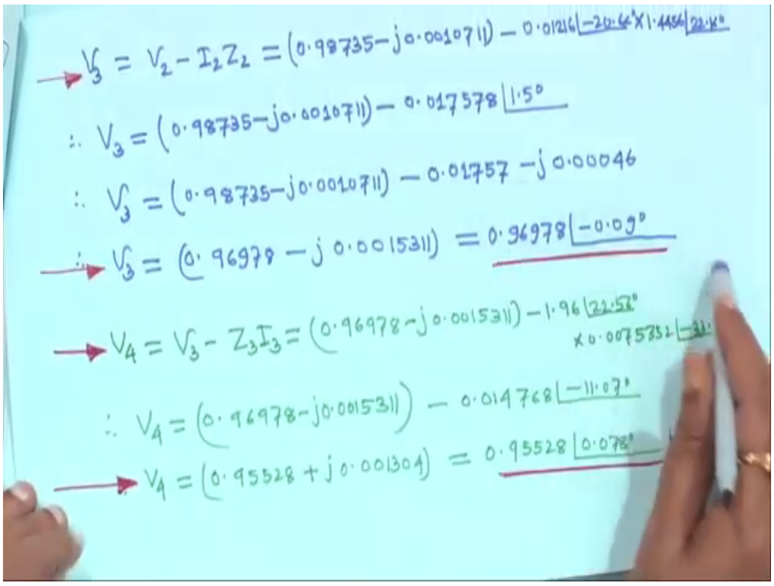

Similarly, V 3 will be is equal to V 2 minus I 2 Z 2. So, that is actually 0.98735 minus j 0.0010711 minus this is your I 2 and this is your Z 2 values right. You just multiply and simplify. If you multiply and simplify V 3 will become 0.96978 minus j 0.0015311; that is actually 0.96978 angle 0 point minus 0.09 degree.

Similarly, V 4 if you compute it will result V 3 minus Z 3 right and this value of V 3 you put it here; here we are putting it here this value of V 3 right and then minus your I 3 into your this is your I 3 as this is your Z 3 and this is your I 3 right. So, if you simplify all this thing then it will become actually 0.95528 angle 0.078 degree per unit. This is that after second iteration this is the voltage magnitude right. So, this is only when your concave your taking capacitors. Therefore just see the competition.

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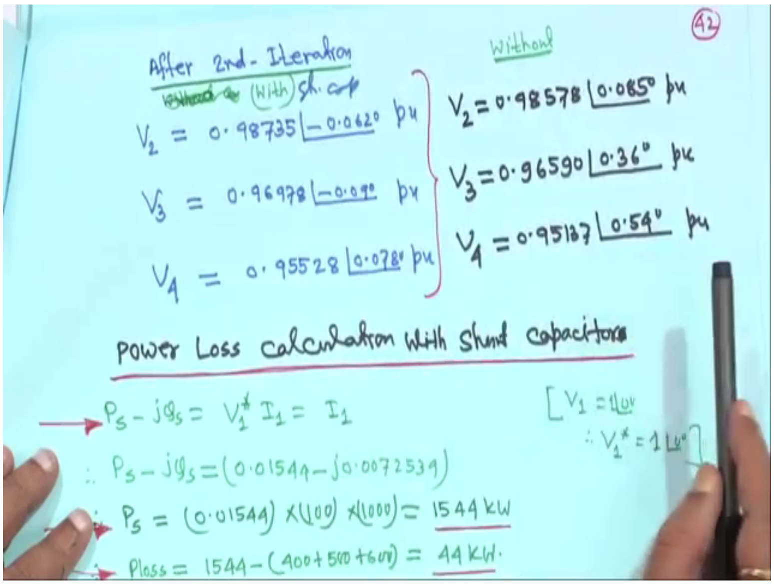

This is after second iteration this is with shunt capacitor right this is with shunt capacitor. So, after second iteration V 2 is 0.98735, here it is 0.98578. So, there is a slight improvement I mean because this is a small system. So, voltage improvement is here because it is 578; it is 735 right.

Similarly, that your without capacitor it was 0.96590; this we have seen it, when you are doing the load flow method of the first method right only from this results are taking from the first method after second iteration. So, here it is 0.96590 angle 0.36 degree; here it is 96590.96978. So, voltage has improved.

Similarly this one it is 0.95137 but here it is 0.95528; here also it is improved. So, everywhere voltage actually has improved and because of the capacitor although not all the time it will happen but for this example, this angle was leading, here it was lagging, here it is leading, here it is lagging, here it was leading, here also it is leading but there is some change in the angle also.

So, this is your what you call that after second iteration the voltage. Now, whenever you put shunt capacitor. So, we except that power loss will be less that there will be less power loss. So, after second iteration I will ask you that you should make third iteration and see output at third iteration you will find solution as almost converged.

So, I will request you to make third iteration and check this. So, this thing I have told you that net power injected at the substation. Already I have told you that is P s minus j Q s is equal to V 1 conjugate I 1; that is V 1 conjugate V 1 is equal to 1 angle 0. So, V 1 conjugate is also 1 angle 0. So, basically it is equal I 1. Therefore, P s minus j Q is I 1 is this much after second iteration these value is after second iteration right. So, P s is the real part of this one; so 0.01544 because this is in per unit megawatt.

So, multiply by base MBV 100 time multiplied; then you 1000 I am multiplied. So, all this thing it is coming 154 1544 kilowatt right. Therefore, P loss P loss will be this is that power injected at the substation I have told you minus that sum of all the loads. So, 400 kilowatt plus 500 kilowatt plus 600 kilowatt; these are node 2, these are node 3, these are node 4. So, ultimately loss is coming 44 kilowatt. So, when we are when we are taking without capacitor that that initial load studies that using this method it was coming 57 point something it was coming. So but here it was forty four; that means, loss has decreased due to the shunt capacitor placement right.

Similarly Q loss is your similar way you find out this is your Q s is equal to actually 0.0 072539 P o. So, that you multiply by 10 to the power 5 because 100 MBV base and 1000 right in terms of kilowatt because you want at kilowatt. So, basically it will be 725.39 and reactive load will be your node 2 and node 4 because 3 is compensated right. So, basically it will be 300 plus 400, 700. So, it is coming 25.39 kilowatt but original one I think we got 26 or 27, but here it was reduced because at the same time your line reactance was also your what you call less compared to the resistor; I mean if you take r minus x ratios right. So, here also reduced here also loss is reduced.

So, this is your what you call this that your shunt your what you call reducing of shunt capacitor using of shunt capacitor in the loss reduction in the significant. And that is why I told you again and again that sometimes we feel that shunt capacitors perhaps it improves the voltage level; no. The basic idea of shunt capacitor is you will if you I mean is that is objective is to reduce the power loss. This is the primary objective right all right.

The secondary objective is do not much it improves the voltage level right. It improves, but all though it will it will not like series capacitor, but whereas this one your shunt capacitor it actually reduce the power losses in the network. So, if you go to any substation anywhere, particularly you will see all though it is there on the 33 kVA side or 66 kVA side also it may be there but in distribution in distribution system also you will find that utilities all over the world they are putting shunt capacitor at least 2, 3, 4 shunt capacitors are putting, for that they find out the best location. Just a just you have a distribution network say a 100 20 nodes distribution network I mean large distribution network.

And there just arbitrarily you cannot put shunt capacitor. Then instead of gaining you will be loser also may also increase also because if you put in you know not an optimal place. So, in the class room exercise I cannot teach you that optimality and other thing but I will tell you at the end of all this thing that how one can do a optimal thing.

If you have a if you have a load flow program you can easily make it; you at least using analytical method. So, this is what that shunt capacitor where it is that loss reduction is the significant in shunt capacitor right. So, this is this is regarding shunt capacitor.

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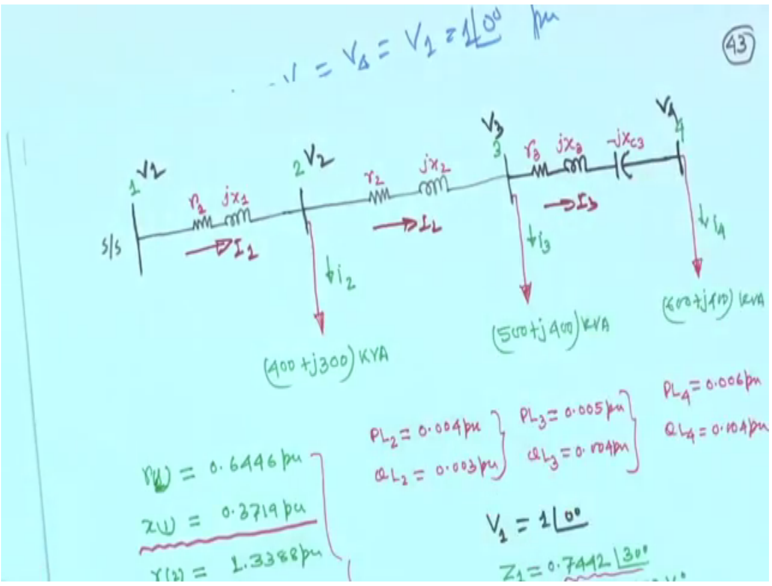

Now, with for the same example just for the purpose of your understanding, what I will do for the same example I have taken a series capacitor also and in the case of series with the same example I have written r 1, x1, r 2, x 2, r 3, x 3 just to show that series capacitors somewhere in distribution line connected, but same Z 1, Z 2, Z 3 value will be used identical thing. Throughout this thing just to have a feeling same parameters are used right. Now, what per in the case of series capacitor I have made a series capacitor connected in branch 3 that is here only here only right.

So; that means, it is given minus j x 3. So, this is the this is the current; this is the current this branch is i 1; this is it i 2 right and this branch current is i 3 right. So, question is that this loads are same this loads are same 400 plus j 300, 500 plus j 400, 600 plus j 400, but there is no shunt capacitor also. When you take the series capacitor rather than kilowatt you have to consider that your reactance of the your what you call that series capacitor.

So, because that if you if you take Q c 3; it will be basically I square x c 3; if load is changing I will change the Q will vary right it acts like a voltage regulator. So, in that case in that is why this x 3 this r 1; this your sorry this is r 1 x 1, r 2 x 2 and r 3 x 3 right this all this thing you take in per unit then x 33 x c 3 also you take it per unit because it is series that is why it has been taken.

So, from the common sense it suggests that if I put capacitor here then voltage of this node will improved because for this branch the reactance will decrease because it will be r 3 plus j x 3 minus x c 3. So, because of that reactance of this branch will decrease. So, V 4 voltage will increase, but in this side that V 2 V 3 it will not be affected that way right because it is it is a connected here. So, before proceeding to this I will suggest you when you take this problem you put the same capacitor here, whatever value I have taken you put the capacitor.

Here then you will see voltage of this node will increase successively; 3, 4 all the voltages will increase right. So, that was the that, but just for your understanding I have taken here this your x c 3 and here you will also see that i 1, i 2 there will be not much change; even i 3 also there will be not much change in the current but voltage improvement will be there.

But it is a very small system. So, I cannot guarantee a large improvement of voltage, but if you take a realistic network right I mean which are network which are your physically your what you call existing those network if you take and if you can verify this.

But let me tell you in distribution system that your series capacitors are not being used due to some reason. But you have to see this right. So, this parameters r 1 x 1, r 2 x 2 and r 3 x 3 this all are in per unit and same parameters are taken same loads are taken for your understanding. So, in per unit I am writing P L 2 is equal to 0.004 p u; Q L 2 is equal to in terms of per unit 0.003 per unit.

So, P L 3 is equal to 0.005 per unit and Q L 3 is equal to 004 per unit and P L 4 0.006 per unit and Q L 4 is equal to 0.004 per unit and substation voltage V 1 this one is 1 angle 0 and what your voltage? Voltage this is this voltage is V 1 this voltage is V 2; this voltage is V 3 and this node voltage is V 4 right

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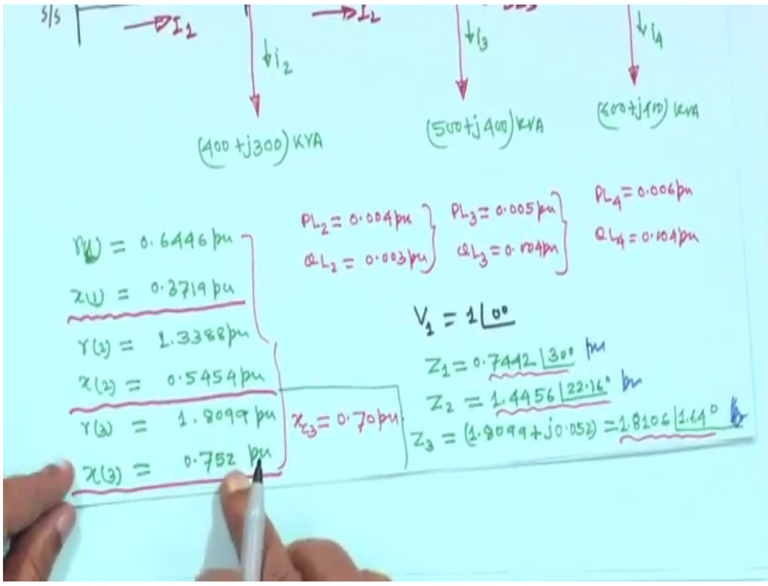

So, and Z 1, Z 2 and Z 3; Z 1 is point same value. 0.77442 angle 30 degree per unit. These are all per unit right; I am not written, but throughout the thing we have written all per unit right; all per unit and Z 3 is equal to 1.8106 one point because Z 3 it will decrease because earlier it was it was your x 3 is equal to 0.758, but x 3 we have taken; x 3 we have taken 0.70 say per unit we have taken.

Therefore, x 3 minus x c 3 it will become your 0.052. So, Z 3 it has decreased 1, earlier it was 1.89, now it is 1.8106 angle 1.6 degree right.

Thank you.