Power System Engineering

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Lecture – 39
Application of capacitors in distribution system

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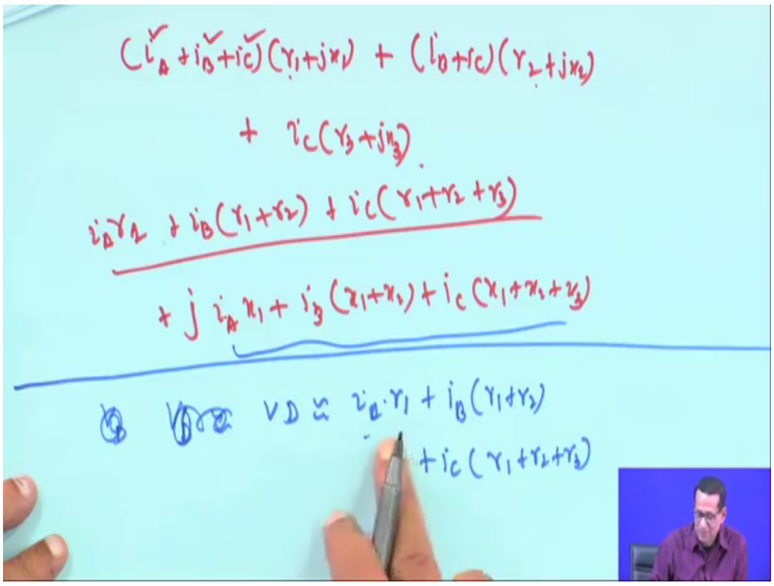

So, that is why the voltage drop that equation actually it is approximate right, actually this is your i a into r 1 only this term we are writing plus i B into r 1 plus r 2 plus i c into r 1 plus r 2 plus r 3 right, but this magnitude this other term this term we have not considered.

Generally, in a distribution system this r values are higher than a ratio of r by x always greater than 1 right. So, that is why this values are was small r that is why we did not consider, but exact computation later I will show you. I we have made it using calculating voltages v a, v b, v c everything, but that is why approximate calculation that that if you want to make approximate voltage drop so, this will be the formula v D will be i your for that example it will be your i a i.

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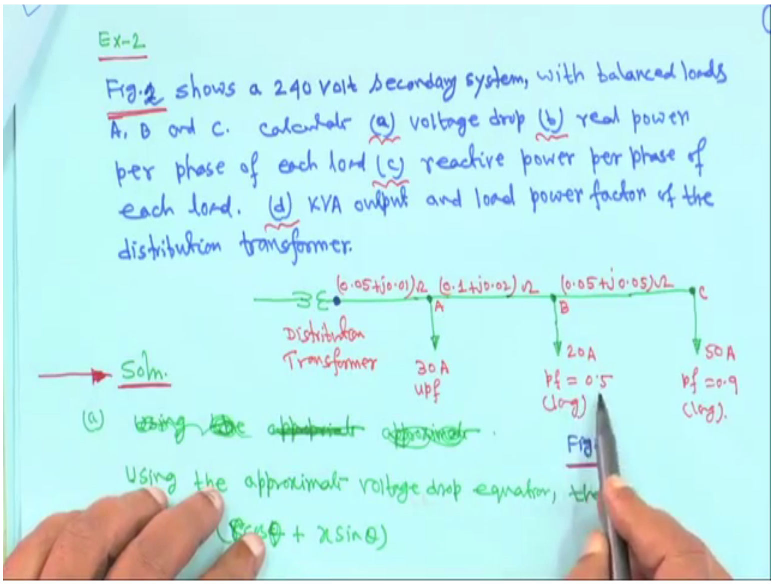

This is the current i A going 30 ampere into r 1 then plus your i B into r 1 plus r 2 then i C into r 1 plus r 2 plus r 3 whatever it is coming here from this from this derivation right.

So, that is why that approximate method actually we do not use that complex term complex term will be very small. So, total that mean total voltage drop 14.264 volt means that at distribution this is taking for 240 volt just refer your understanding.

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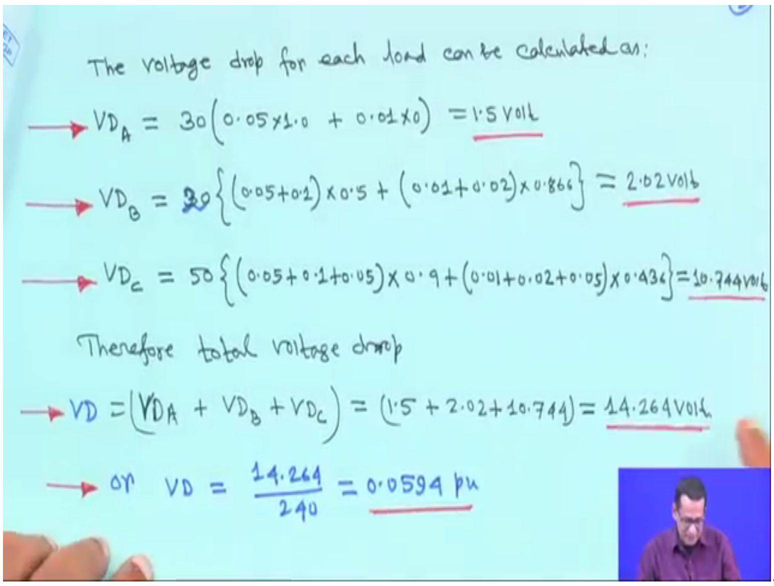
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So, this point voltage actually 240 volt the secondary side of the transformer; that means, at the total voltage drop is 14.264 means that there are tail end of the feeder that mean here at point C, the voltage will be 240 because it is given 240 minus 14.264, that will be the voltage at this point right

So, that is the total voltage drop of the line that is why it is in per unit it will be 0.0594 per unit right.

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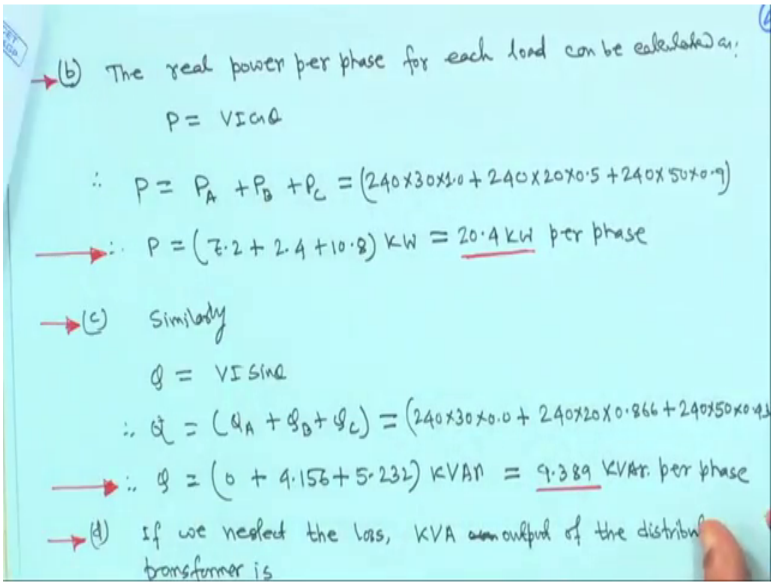

This is the total voltage drop that is there at the end of the feeder the voltage will be actually 240 minus this one that is at point C right. So, that and this way next one you have to compute the real power. The real power per phase for each load can be calculated P is equal to VI cos theta right.

So, it is per phase only we are computing so, P A plus P B plus P C so, VI for first load it is VI cos theta it is 1, second load i is 20 ampere VI cos theta is 0.5 given everything is given, your everything is given you mean to power factor lagging power factor for this one this one all data are given. This turn that only we are putting and then VI ,V is 240 all the time 50 into 0.9 right.

So, this way that total power will be 7.2 plus 2.4 plus 10.8 kilowatt that is 20.4 kilowatt per phase. This is approximate one, this is approximate one why that everywhere you are taking the voltage is 240 volt right this is approximate one that every node voltage is actually 240 volt. That is approximate one approximate one right so, but if you calculate voltage it will be different right. Similarly, Q is equal to in general VI sin theta that is Q A plus Q B plus Q C that is 240 into 30 into your cos theta 1 sin theta 0 plus 240 into 20 the current into sin theta 0.866 plus 240 into 50 the current into sin theta 0.436 if you compute it is 9.389 kilo hour per phase right.

Now, if you neglect the loss the KVA output of the distribution transformer suppose loss is neglected no loss is there. So, this is my P and this is my Q right.

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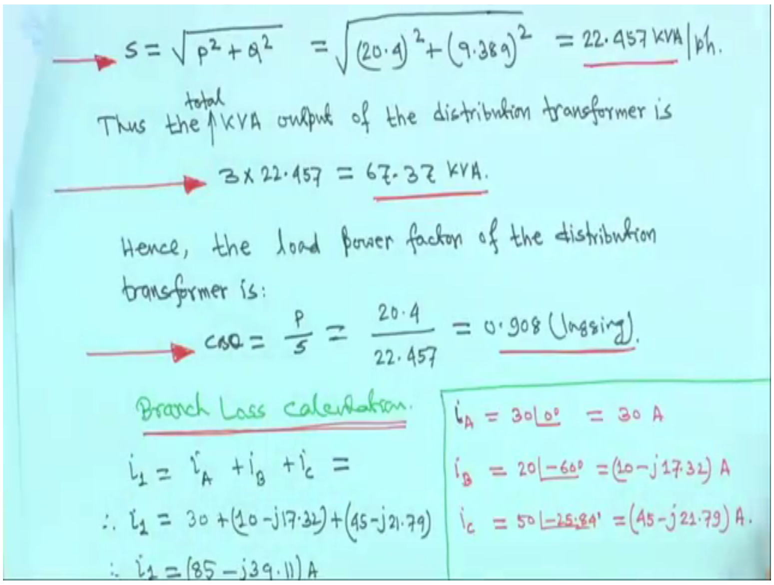

Therefore S is equal to root over P square plus Q square. So, P is coming 20.4 and Q is coming 9.389 these are all these are all these calculations. Actually I have made on the rated value because we have to plan the distribution transformer your what you call rating, but if you go for calculation you will find v a, v b, v c voltages are less than 240, but for the planning stage and approximate one will be all voltages are taken same right. So; that means, it is coming 22.457 KVA per phase right.

Therefore, the total KVA output of the distribution transformer is it is 3 phase so, 3 into 22.457 therefore, 67.37 KVA right. Hence the load power factor of the distribution transformer will be cos theta is equal to P upon S. P is 20.4, S is equal to 22.457 so, it is coming 0.908 lagging power factor right.

So, now branch loss calculation these are the current given at these your what you call in this diagram, it is this current actually this current is i A, this current is i A, this is i B and this is i C at node thing right. Here I am not putting i A, i B, i C, but understandable right. So, here it is i A is equal to 30 angle 0 because unity power factor it was i B is equal to 20 angle minus 60 power factor lagging 0.5. So, it is 10 minus j 17.32 ampere and i C is equal to 50 angle minus 25.84 degree that is 45 minus j 21.79 ampere right. Therefore, first branch current i 1 is equal to i A plus i B plus i C right. So, this branch current i 1 right here I have, here I have used small i 1 there should not be any confusion for you better I should make it capital I 1 capital I one right.

So, I 1 is equal to i A plus i B plus i C because these branch current will be i A plus i B plus i C sum it up all right so, if you i A, i B, i C you substitute it will be 85 minus j 39.11 ampere right.

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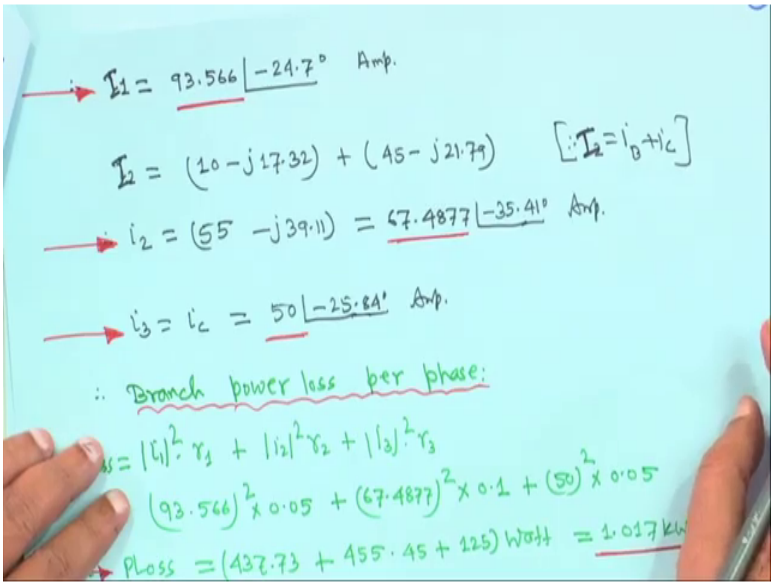

Next is so; that means, i 1 I will make capital 1 there should not be any confusion capital I 1 is equal to it will come 93.566 minus 24.7 ampere. Similarly, current in branch 2 actually I 1 I 2 means these branch, I better I should read out this diagram right then things will be easier for you better I should read out instead of instead of spoiling this diagram I am redrawing for you.

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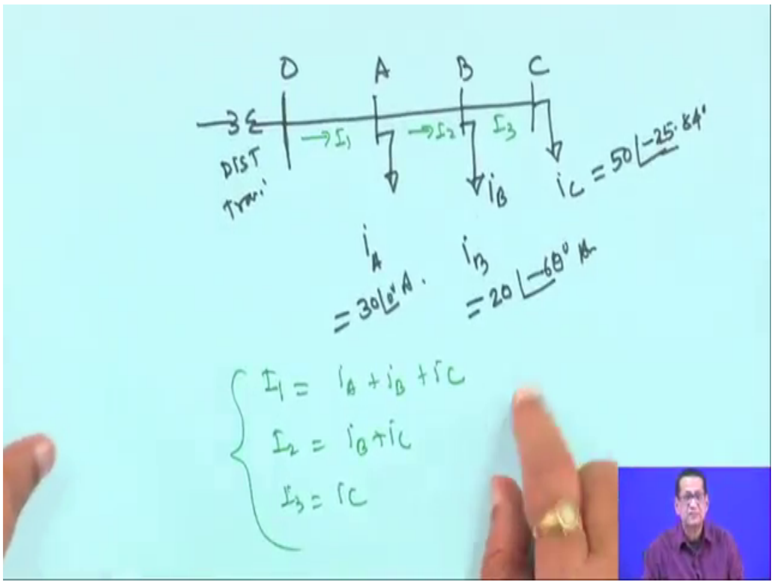

Suppose you have a distribution transformer right these are your node, this is point A, point, B point, C. This is A, this is B and this is C, this is O right. This is your distribution transformer right and here the current is there your i A is equal to it is given 30 angle zero because unity power factor. This is current B, it is your i B, i B is given your 20 right 20 magnitude and power factor is your it is minus 60 degree minus 60 degree ampere right and this is your i C right and this is your i C, i C is given 50 and cos theta is equal to 0.9 so, it is minus 25.84 degree right.

This is actually your what you call that current i B, i B, i C so, this through this current flowing is I 1, this is I 2 and this is I 3 right; that means, you have just now you have seen know I 1 is equal to this is; that means, your i A plus i B plus i C. I 2 is equal to i B plus i C and I 3 is equal to i C right so, this is the thing actually. So, whenever we are computing this one right. So, this is your I 1, I 2 all have been shown and next this I 2 right. So, this is your value of I 2 is 10 similarly I 2 is equal to i B, this is actually i B this is actually i C right.

So, here it is capital here you make capital so, there should not be any confusion. So, it is i B and it is i C if you add it will become 67.4877 angle minus 35.41 degree ampere right and I 3 is equal to i C right so, make it capital I 3 is equal to i C so, it is 50 angle minus 25.84 degree ampere right. So, branch power loss so, it will be capital I 1 square, capital I 2 square and capital I 3 square right so, all I 1, I 2, and I 3 magnitude are known r 1, r 2, r 3 magnitude all values are known. So, put it here and if you simplify it will become 1.017 kilowatt per phase right. This is your P loss, similarly for Q loss it will be here I have written I capital I 1 square x 1 plus capital I 2 square x 2 plus capital I 3 square x 3 right.

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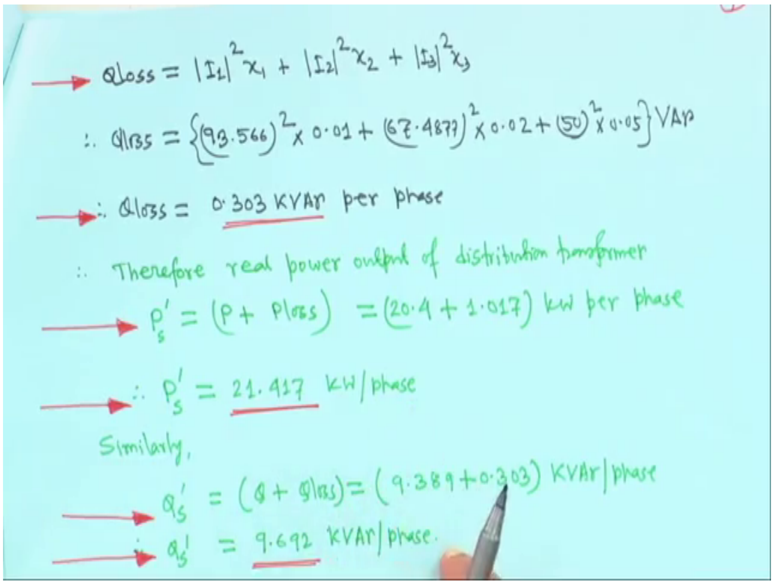

So, Q loss will be substituted all the values of I 1 and x 1 x 2 x 3 everything so, it will coming actually this is VAr converted to kilo VAr. It is Q loss is 0.303 kilo VAr per phase right. Therefore, real power output of the distribution transformer that is say I making P s dash actually it should be P plus Ploss because load plus loss it has to supply so, it is coming actually 20.40 plus 1.017 kilowatt per phase that is 21.417 kilowatt per phase.

Similarly, reactive power it will be Q plus Qloss we already this P value earlier we got this Q value earlier we got 9.389 plus 0.303 kilo VAr pre phase; that means, Q s dash is equal to 9.692 kilo VAr per phase so, this is P s dash and this is Q s dash right.

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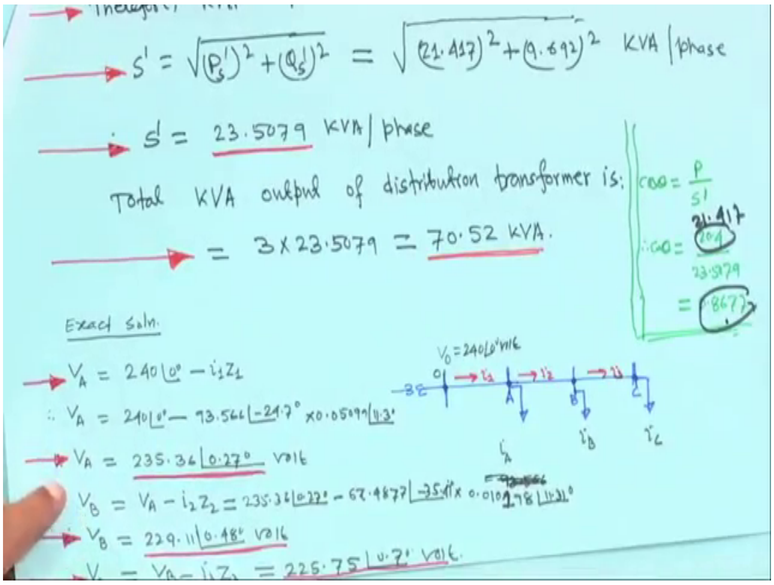

Therefore KVA output of the distribution transformer is so, S dash is equal to root over P s dash square plus Q s dash square. So, it is actually 21.417 square plus 9.692 square so, KVA per phase, it is coming 23.5079 KVA per phase. So, for 3 phase transformer if you multiply it will be 70.50 KVA multiply by 3 previously we saw it is approximately 67, but that was loss ignore, but as soon as you have to you are considering the loss it is coming 70.52 KVA. Therefore, power factor will be actually P by S dash.

So, 20.4 divided by your this thing 23.5079 so, it is a 0.8677, but at substation power factor actually it is whatever we have taken the load actually it will become your this what you call this P S dash it is 21.417. So, power factor of the substation instead of 20.4 load you should take 21.417 right so, almost so, this is this value is based on this 20.4, but actually I have missed this one. Actually, it should have been 21.417 so, please calculate it will be nearly 0.9 it I do not have calculator here, but it will be nearly 0.9 right.

So, and exact solution if you want then for this your what you call for this node. So, V A actually substation voltage is 240 angle 0 minus your i 1 Z 1, this is I should make capital I 1 Z 1. So, I 1 is known Z one is also known everything is given all data all parameters everything is here all this is Z 1, this is Z 2, this is z 3 right. Z 1, Z 2, Z 3 so, if you sum simplify you will find V A will become 235.36 angle 0.27 degree volt you check all the calculations I hope all these calculations are correct, but you should check it.

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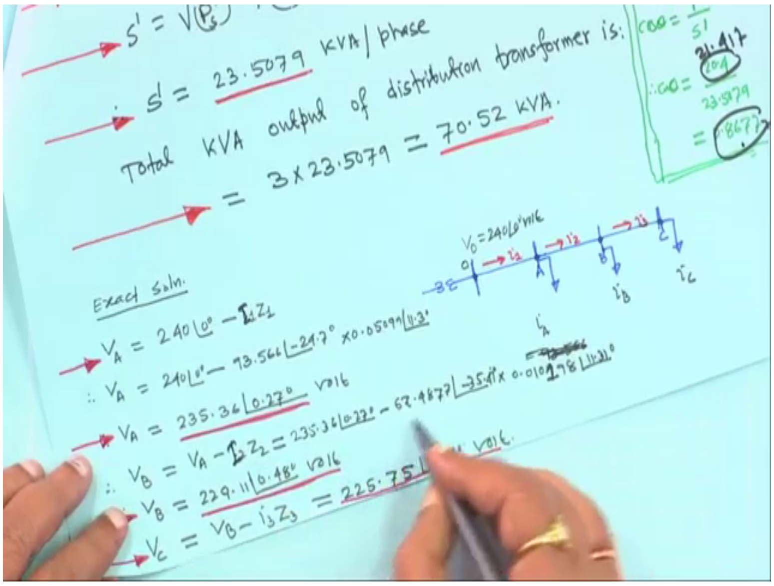

Similarly, V B is equal to V A minus your capital I 2, I 2, Z 2 if you simplify it will become V B is equal to 229. your what you call 11 angle 0.48 degree volt right. Similarly, V C is equal to V B minus I 3 Z 3 you substitute this V B value I 3 Z 3 value, you will get actually 225.75 angle 0.7 degree volt right, to all the all the node voltage at A, B, C, you will get this much, but earlier; that means, end point voltage what 225.75.

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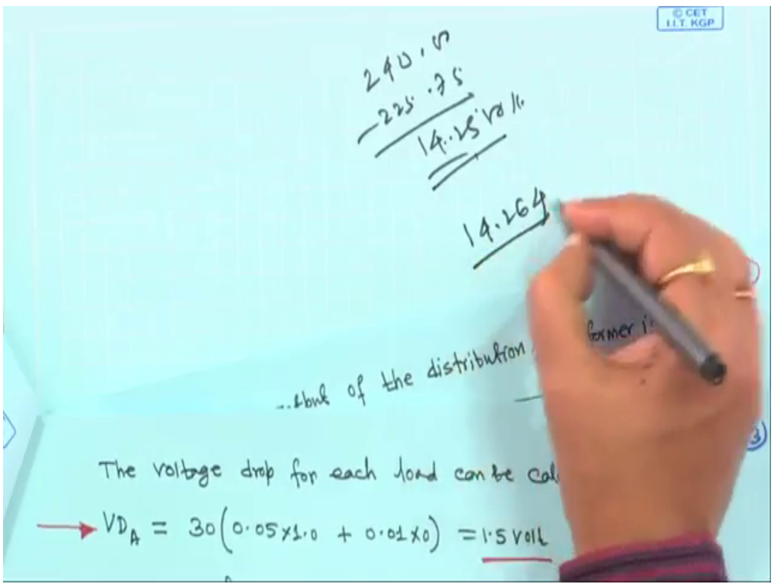

So, in substation voltage was 240.00 and this is 225.75 if you subtract here right so, it will be 14.25 volt right. So, this one we got using this your what you call using that your voltage calculation because it is no iteration here because all currents are known to you and earlier for voltage drop method voltage drop how much you have got 14.264.

So, here it is coming 14.25 and ultimately here it is coming 14.264, this is the approximate method. This is that approximate method we got 14.264 and it is 14.25. So, it is it is as accurate as anything right for this small system.

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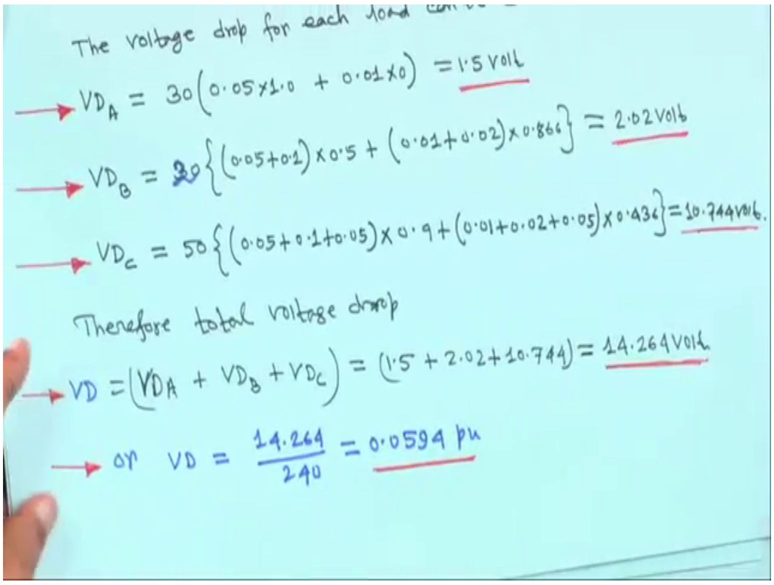

So, that is why that approximate formula is used for distribution system right.

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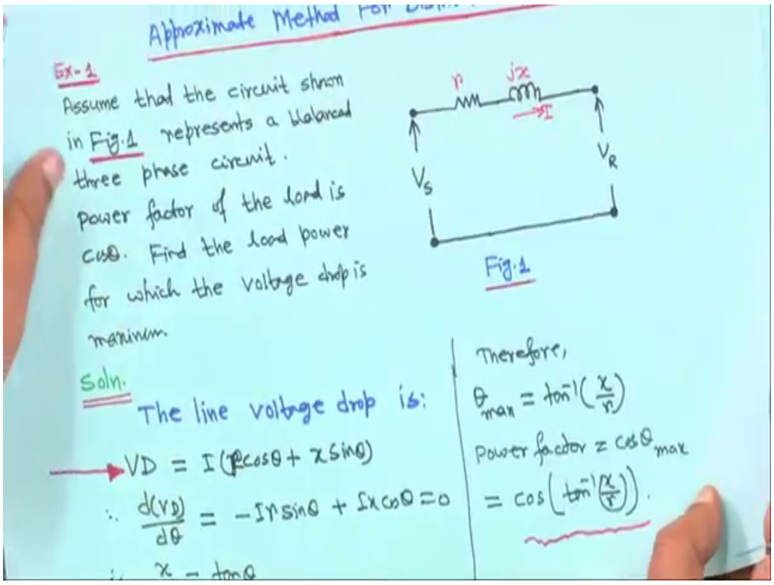

With this that some idea, I have given you regarding approximate method for distribution system analysis right. After this what will happen we will move to your what you call application of capacitor to distribution system, here things will be interesting, but you have to you have to understand many things. Before proceeding all the basic one or two thing I would like to explain at the beginning itself right. Although, whatever problem we will consider in that you are in this course that will be as far as possible classroom your what you call that classroom exercise.

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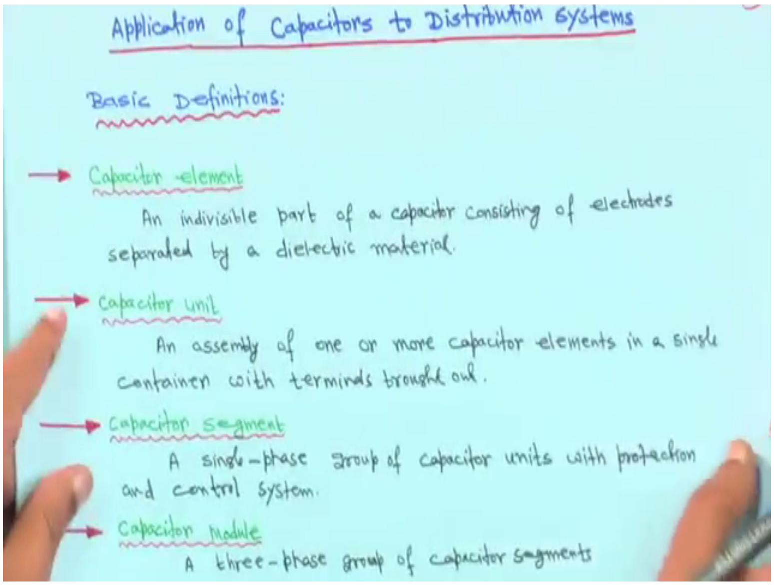

So, suppose you have a distribution network look you just try to understand first that it will be application of capacitor to distribution system, this will be the headline that application of capacitor to distribution system I will come to that all this thing later, but before that certain things you have to understand.

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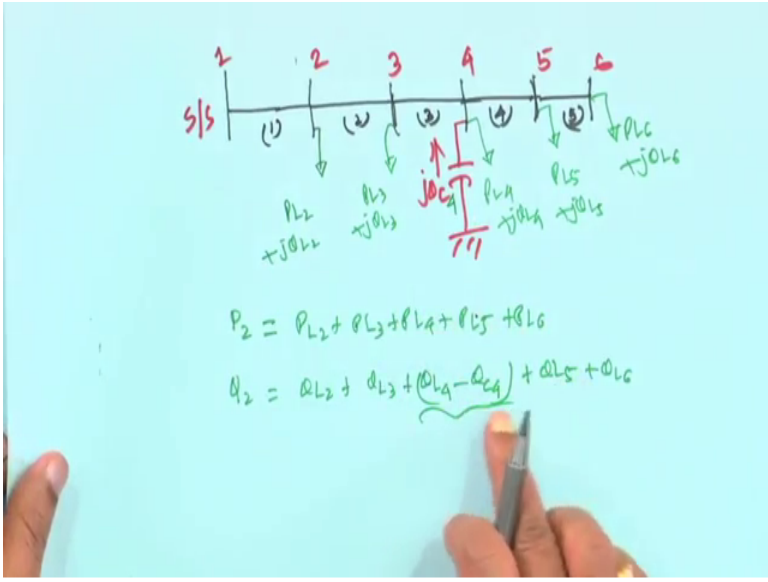

Although, bigger problem cannot be taken but you should make your concept clear at the here itself right so, suppose this is the thing.

Suppose you have first thing the concept of the lagging leading load, then little bit of because it is a capacitor application problem, but little bit of distribution generation also how it can be incorporated some ideas right. For example, suppose you take any node right you take a you take any node. For example, you take any node suppose this is your some node right here.

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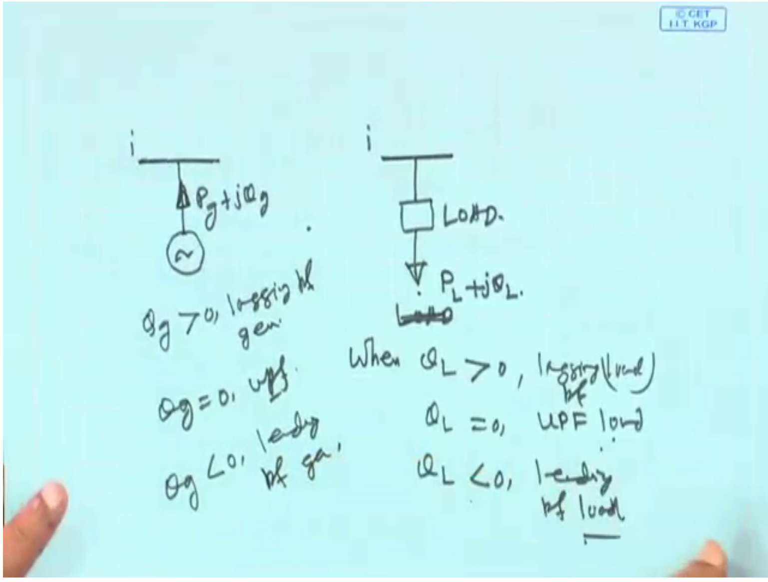

You have a load here you have a load this is your load right or I can put it here this is your load right and this is sum node sum node sum node I say I right. Suppose you have load here is suppose P L plus j Q L right, this is the load. Now, when this you have to understand when Q L understand means simple thing you have to keep it when Q L greater than 0. I mean Q L is positive, but look the load is absorbing power arrow direction is downward, arrow direction is downward mean the load is absorbing power. So, when Q L greater than 0 it is actually lagging load right.

So, and when Q l equal to 0 then Q L zero means it is real load that is unity power factor load so, is in short we call it is UPF load that is your unity power factor load right and when Q L is negative that is Q L is negative less than 0. So, it is leading power factor load right so, this is lagging power factor load. This is unity when Q L is positive it is lagging power factor load, when Q L is 0, it is unity power factor load and when Q L negative, it is leading power factor load right so, this is for the load point of view right.

Now, suppose I am show you suppose another thing is there suppose you have another node say node i for example, some node. Suppose you have a you have a source right suppose, you have a source its source may be renewable base whatever it is. It's suppose you are connecting it to AC network right. So, whatever it is it has been converted to even in DC also for example, solar PV that you are converting by using inverter through the AC thing right. But our objective is only thing that if it is a power being injected into the network or any bus if it is suppose this is P g and this is plus j Q g; that means, arrow is this direction arrow is upward; that means, it is injecting power it is injecting power right. In that case if here Q g greater than 0; that means, it is lagging generation right.

So, or instead of if it is a distributor generation it will be lagging D g right so, lagging generation only both are same whatever I will write both are same, only directions are different here power being injected here power being observed right. So, this is lagging generation when Q g is equal to 0 it is unity power factor thing right so; that means, there is there is no reactive power only real power being injected. So, it is your unity power factor generation right.

Similarly, when Q g negative it is actually leading it is lagging power factor generation it is unity power factor generation and this is leading power factor generation right. So, both the cases things are same here it is Q L greater than 0 less than only thing is that, in the case of load it is absorbing power, in the case of generation it is injecting power it is power supplying to the network right. So, now, if it is so, suppose you have a common node where P load and generation both are there right, if it is a common node if load and generation both are there.

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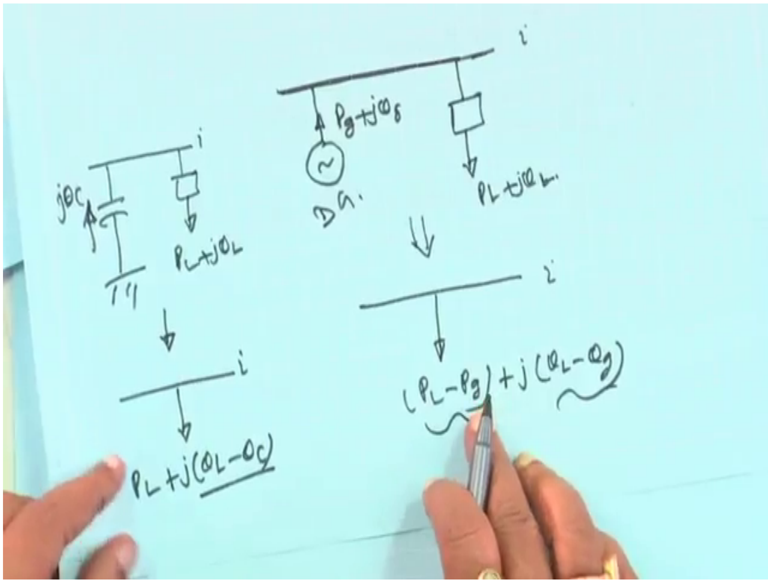

Suppose this is your this is your bus bar right say bus i say this is your load this is your load, this is your P L plus j Q L this is the load right and this is same bus bar suppose generation is connected right. This is P g plus j Q, this is downward this is upward now what will be a resultant of this two. So, resultant of this two in the in the downward direction right suppose this is bus i and resultant should be in the downward direction. It will be like this P L minus P g because it is upward you are taking downward so, it will be negative sign plus j your Q L minus Q g right. So, this is that your resultant right

So, question is that P L minus P g may be negative does not matter, it does not mean that it will be positive it will be negative, Q L minus Q g also it may become negative it does not matter positive or negative this one also positive or negative it does not matter right. So, in the so, this is actually what you call in the case of your some generation some power is injected. For example, this is a distributed generation D G the power being injected. So, this is the concept of power injection in the load flow studies or in a small thing you take you have to take like this.

Now, instead of instead of your what you call D G suppose instead of if it is a if it is a capacitor, if it is some capacitor say suppose this is your load this is your load this is load i say this is your P L plus j Q L and this is your capacitor this is your capacitor. So, it is j Q C being in your j Q C so, Q C is being injected right. So, resultant of this one result of the this one this is bus i right. In the direction it will be P L only here no question of real power right. So, it is P L plus in this direction Q L minus Q C; that means, that reactive power actually is getting reduced, but P L will remain same; that means, in this expression if P g is 0 in this expression if P g is 0 and Q g replaced by Q C you will get this one.

So; that means, this is the your what you call that load flow studies if you consider a D G the concept will be like this, if it is a capacitor it will be like this. So, that is why before your what you call going to the application of capacitor this much I told you that will be the concept.

Second thing is second thing is suppose you have a network take radial network only. Take one more node first you understand all this later we will find you have taken all the simplest thing from the classroom point of view right. Suppose, this is your this is your substation this is bus 2, bus 3, bus 4, bus 5 there are 6 bus right. So, as our objective in our capacitor suppose we have connected a capacitor here right. So, Q C is being injected Q C is being injected, j Q C we are making it right and everywhere the load is there load is there everywhere this is your P L 2 plus j Q L 2 here also load is there P L 3 plus j Q L

3 load is there here also load is there, P L 4 plus j Q L 4 along with that capacitor is connected at load 4. So, here also load is there P L 5 plus j Q L 5 and here also P L 6 plus j Q L 6 it is load is there right.

So, in that case in that case this is then what will be the effect of first you have to understand, What is the effect of capacitor? Now, if you think forget about losses all there are 5 branches 1, 2, 3, 4, 5 suppose there are 5 branches you forget about the branch losses say there is no branch loss right. Now, if you think that will be the electrical equivalent you take this is branch 1 this is say branch 2 now branch 3, branch 4 and this is branch 5 right there are 5 branches.

So, if you take electrical equivalent of branch one then what is P 2 right and what is Q 2 P 2 will be for branch 1 or electrical equivalent of branch 1. So, total load phase through the load P 2 will be you will be P L 2 plus P L 3 plus P L 4 plus P L 5 plus P L 6 right 2, 3, 4, 5, 6, 2, 3, 4, 5, 6. This is P 2 now what will be Q 2, Q 2 will be first Q L 2 plus Q L 3 plus come to here Q L 4 right. I told you that just now I told you that A B here Q C is connected it will P L 4 plus j Q L 4 min[us]- j Q L minus Q C just I told that it will be P L plus j Q L minus Q C.

So, here that resultant reactive load in the direction of the load right in the direction of the load it will be actually put here Q C 4, that is better at node 4 Q C 4. So, it will be Q L 4 minus Q C 4. So, it will be Q L 4 minus Q C 4 right plus your Q L 5 plus Q L 6. So, here the change right all the basically Q L 2, Q L 3, Q L 4, Q L 5, Q L 6, but this being injected so, it will be your Q C 4. Similarly, first you have to understand similarly if you come to your P 3 it will be again P L 3, plus P L 4, plus P L 5, plus P L 6. So, I am not writing P 3 our my objective is to Q because cap Q is being injected. Similarly, P 4 will be P L 4, P L 5, P L 6, P 5 will be P L 5, P L 6 and P 6 will be P L 6 this is understandable, this is understandable.

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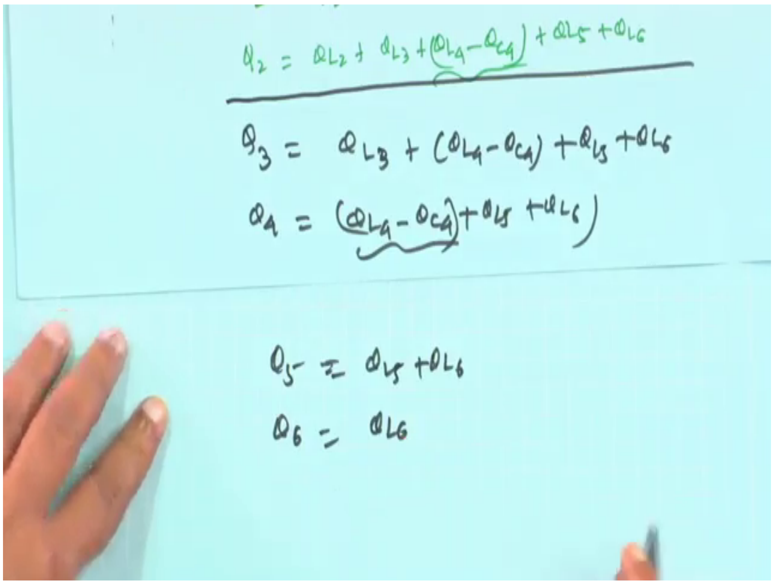

Now, if you write so, I am writing only Q, Q 3 will be again Q L 3 only this one will be dropped Q L 3 plus Q L 4 minus Q C 4 plus Q L 5 plus Q L 6 right that is Q 3. If you write Q 3 Q 4 that is your Q 4 so, this term will be dropped this term will be dropped it will be Q L 4 minus Q C 4 plus Q L 5 plus Q L 6 right. So, up to Q 4 it is fine, up to Q 4 it is fine. Now, next is if you write Q 5, What is Q 5? Then Q 5 will be these two term for the node 4 this will be dropped is equal to Q L 5 plus Q L 6 and Q 6 will be Q L 6 right.

Now, if you look into that that when this capacitors that connected at node 4 up to node 4 the effect of Q C is there up to node 4 Q 3 also function of Q C 4, Q 3 also of your Q C 4, Q 4 also function of Q 4, Q C 4 right, but as soon as you are coming to 5 you are leaving this you are leaving this node you are leaving this node; that means, your Q 5 is equal to Q L 5 plus Q L 6 because capacitor is behind this node right not ahead of that and Q 6 will be simply Q L 6 that; that means, what does it mean; that means, that whenever you connect a capacitor right.

This capacity I mean institutively or philosophically you can tell this is capacitor when you connect it is Q i C, Q C means it is also injecting current here i C. It is also injecting current here i C say I am just putting i C say this injecting current i C; that means, from the connected node right from the connected because all this things this 2 3 4 all this node from this point it is coming towards the source side right other side it is no effect is there no effect is; that means, this thing actually from connecting node this capacitive thing flowing to this side this current is flowing to this side right.

So, I mean this is the basic philosophy that mean this side 5 and 6 not affected by this capacitor; that means, whatever branch losses will reduce due to capacitor placement because whenever use your sun capacitor right and first is series capacitor if you put it will come to that for a capacitor application, series capacitor actually main purpose is to increase the voltage magnitude right of the each node. That is the function of series capacitor and as the voltage is increased. So, loss power loss is inversely proportional to the square of the voltage magnitude we have seen power loss of branch that is your r into P square plus Q square upon V 2 square so, inversely proportional to the square of the voltage magnitude

So, though you what you call though because, but series capacitor purpose is that it should increase the voltage magnitude right and do not match because of the improvement of the voltage magnitude to some extent power loss, also will reduce or in the case of sun capacitor. It is that main purpose is that your primary objective is that it should reduce the power loss right. It should reduce the power loss, but at the same time that your; what you call that voltage also being improved little bit improved. So, it effect is there also for loss reduction, but here for this branch and this branch there is no effect is coming for the capacitor whether computing P 5 or P 6 there is no effect is coming.

Therefore, in the branch case that will be this there will be no power loss in this two branch due to capacitive current. Only this branch power loss reaction will be there because of the capacitor placement do not match voltage will be improved right because of the because all these 2, 3, 4 node voltage will improve hence 5 and 6 also voltage will improve due to the voltage improvement there will be little bit of loss reduction in branch 4 and branch 5.

So, this is the philosophy now when I am making this your what you call this is this is the current suppose if I make that this is the i C current flowing like this. So, if you take if you if you take the diagram same diagram right just hold down if you take the same diagram same diagram.

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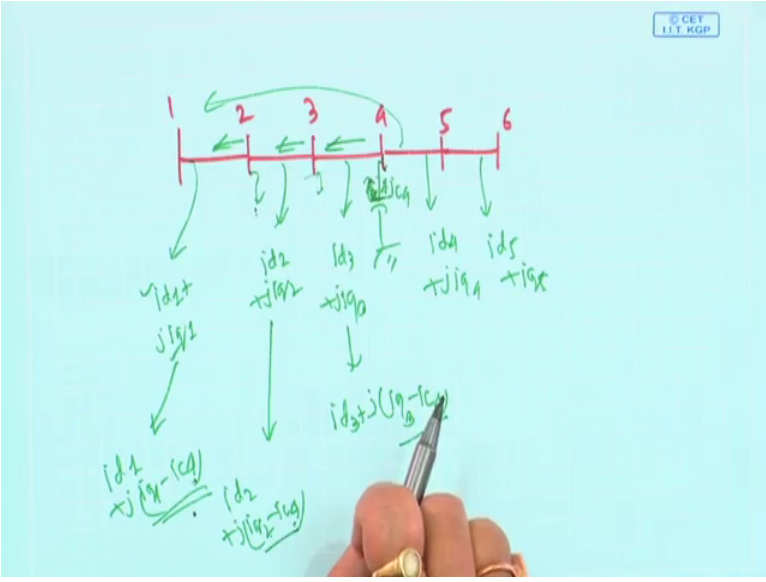

Suppose, this is your 1 this is 2, 3, 4, 5 and 6 there are 6 node 1, 2, 3, 4, 5 the same 6 nodes are there. So, capacitor is connected at node 5 this is the node right so, this is branch 1 branch 2 branch 3 so, current to the branch say it is i d 1 plus j i q 1 say real component of the current and imaginary component of current. This branch current say i 2 is equal to say i d 2 plus j i q 2 if it is lagging i q 2 will be negative does not matter and this branch say current is i d 3 plus j i q 3 right and this branch say branch 4 i d 4 plus j i q 4 and this branch say it is i d 5 plus j i q 5 these are in terms of real and imaginary and this capacitor current is i C. I told you this current will be moving like this.

So, ultimately this branch effective current will be i d 3 plus j i q 3 minus i C 4 this node this is your i C, I can make it i C 4 right because this current will be flowing this when this current will be here, this current actually will become i d 2 plus j i q 2 minus i C 4 right. When it is coming here this current will become i d 1 plus j i q 1 minus i C 4. This will be the your train right because you have connected if i C 4 is 0 it will remain as it is; that means, this i C current actually flowing like this flowing like this flowing like this throughout the source.

But this side there is no effect of capacitor using the load I told you up to node 4 it will be it has affected, but when it is coming here this side actually nothing it is from the connecting node to the source, but as you are moving to the source everywhere load is there, everywhere load is there, everywhere load is there; that means, your this at the branch 1 i d 1 and i q 1 will be higher. Therefore, i q 1 minus i C 4 difference will be your higher, but when you moving here difference of i q 2 minus i C 4 further will be your here it may be higher, but i q 2 will be less because some i q 2 will go to the load. Therefore, some current will go to the load therefore, it will decrease.

But when is very close to the capacitor this i q 3 minus i is the difference will be less; that means, whenever you are connecting a capacitor at any network right it effect is local; that means, that branches which are very close to for distribution system very close to the capacity connecting point theirs loss reduction will be higher right. As you are moving this is small network as if you take a large network as a moving towards there this difference actually there will be not much a decrease right.

So, loss reduction will be less, but capacitor in the vicinity of the connection of the capacitor sun capacitor the loss reduction will be more right. So, this is this is something because just basic thing before we will take simple thing because in the classroom exercise, we cannot show all these without in the help of computer right because we need large network we have to show.

But only thing keep it in your mind that capacitors sun capacitors effect actually it is it is local means in the nearby region power loss reduction will be maximum, but as you are moving far away in terms of percentage loss reduction will be low and main purpose of sun capacitor is, that it will reduce the power loss right and do not match it improves the voltage magnitude because every branch there will be less current. Therefore, less voltage drop right therefore, what you call to some extent voltage will also improve. I will take one small example in detail when we will go right, but these are the basic philosophy.

Thank you very much.