**Power System Engineering**
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**Lecture – 41**
**Application of capacitors in distribution system (Contd.)**

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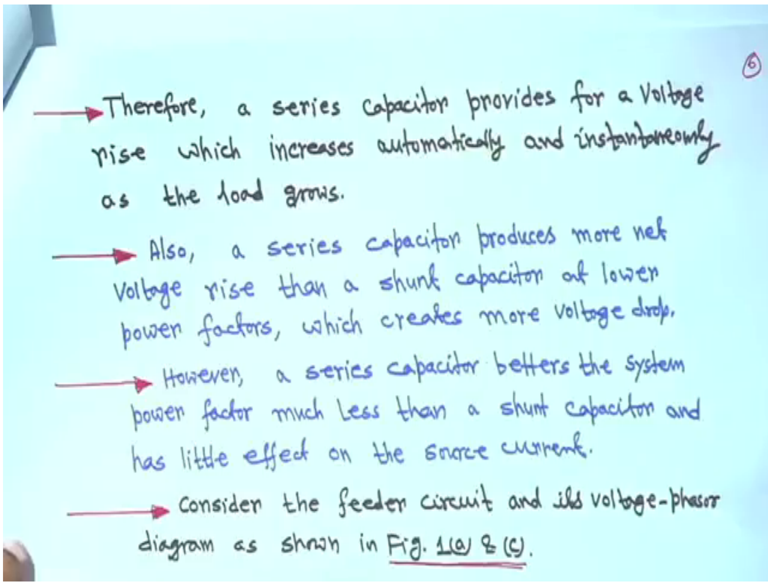


Then therefore, a series capacitor provides for a voltage rise, which increases automatically and instantaneously as the load grows right. So that means, if load increases current I increases. So, that I vary actually. So, QC also will varying that is why it is analogous to some extent that is we call it is analogous to voltage regulator right.

So, also a series capacitor produces more net voltage rise than a shunt capacitor at lower power factor; naturally because it is a series capacitor is basically compensating the voltage drop. So, your what you call that your voltage improvement using series capacitor is much higher and do not much in the shunt capacitor also improve the voltage level but not like the series capacitor right. So however, a series capacitor better the system power factor much less than a shunt capacitor and a little effect on the source current.

So, series capacitor actually has no effect on source current right and it does not improve much to the power factor. Only there is a deduction in power loss because of the voltage improvement right. So, consider the feeder circuit and voltage feeder diagram and so, this is this we have seen figure 1 a and c right.

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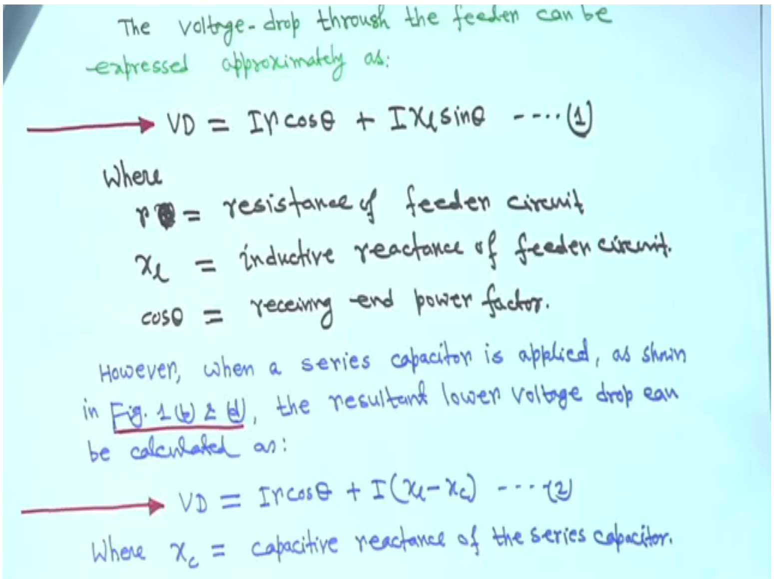


And this is the voltage drop to the feeder can be this we have got, we have seen this diagram, from this diagram we have already shown you that I have made it all this things from this diagram.

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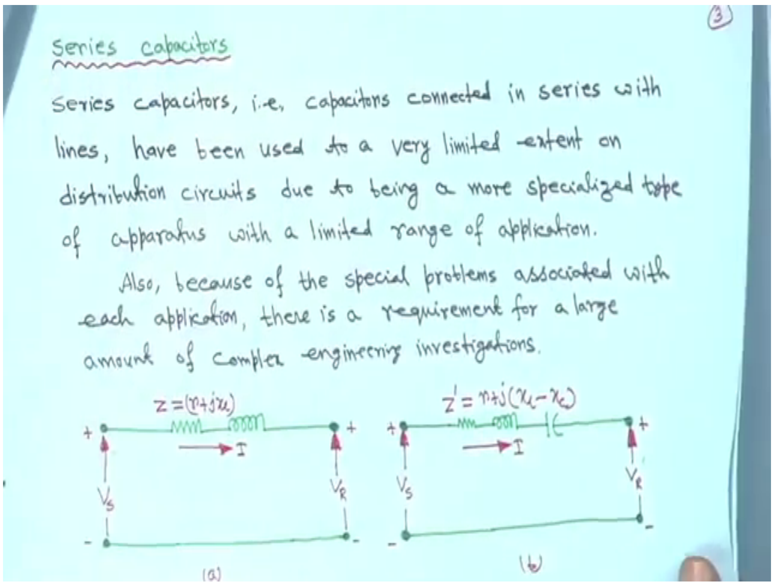


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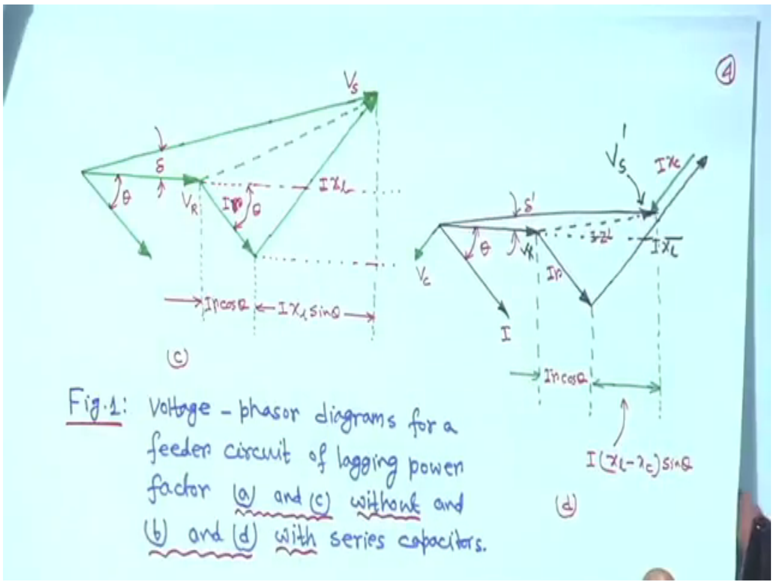


From this diagram the voltage drop actually you have seen it is I r cos theta plus I x l sin theta when series capacitor was not there right, so it is equation 1. Similarly this all the nomenclature is given right. Similarly when for the other part we have also seen the voltage drop approximately is equal to I r cos theta plus I x l minus x c; this is equation 2 right; where x is equal to capacitive reactance of the series capacitor. So, this already we have seen.

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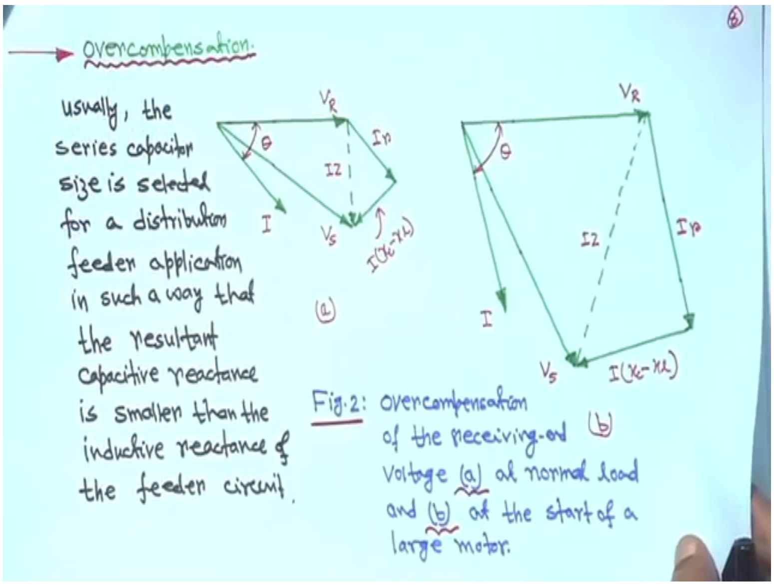


Now next is the overcompensation: So, usually the series capacitor size is elect selected for a distribution feeder application in such a way that the result and capacitive reactance is smaller than the inductive reactance of the feeder circuit. So, if it is over compensation at the receiving and voltage at normal load and at the start of a large motor right. If it is this is the current I lagging current right; if it is over compensation right; that means, your that is x l minus x c is actually becoming negative right; if it is over compensated. So, it is I r will be there.

So, earlier if it is as long as x l less than x c phasor diagram was this side because x l less than x c from this diagram. But if x l greater than x c then it is negative; it will move to this side. That is why this phasor diagram I x l minus x c is to this side right. So, and this is your this angle is never 90 degree right; it cannot be unless and until some special case, but because of my drawing right, but this angle is theta and this is your sending and voltage at the over compensation cases. Now, particularly and second thing is this phasor diagram and the start of a larger motor right.

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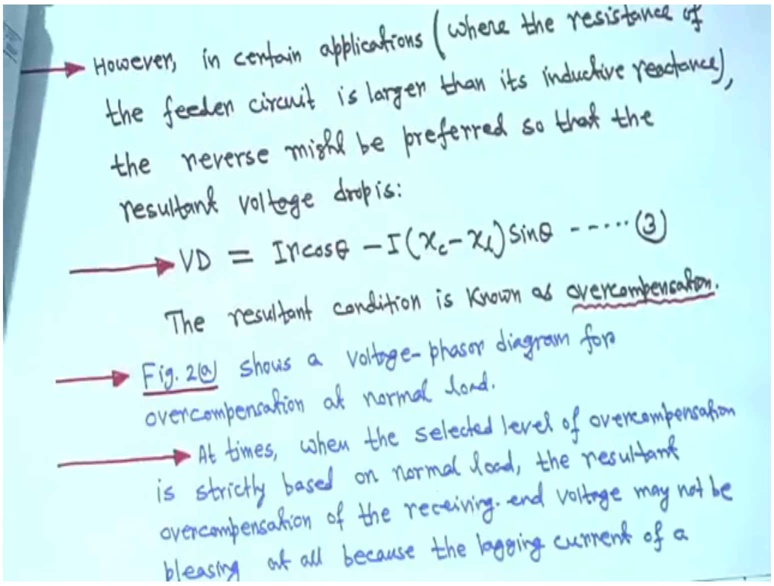


So, ; however, in certain applications where the resistance of the feeder circuit is large and that is inductive reactance right, the reverse might prefer, so that the result and voltage drop will be I r cos theta minus I x c minus x l sin theta right. Because at the start of you perhaps you know that your reverse might be preferred in certain application right. So, in that case suppose it is overcompensated. So, in that case the voltage drop will be I r cos theta minus I x c minus x l sin theta; that mean there will be heavy voltage drop because of this minus sin here right and in that x c greater than x l; remember x c greater than x l. So, the resultant condition is known as overcompensation right. So, figure 2 a is shows the voltage phasor diagram for overcompensation at normal load. This is at the normal load; this is a over compensation case right. Whereas, your what you call at times when the selected level of over compensation strictly based on normal load, the resultant compensation of the receiving end voltage may not be pleasing at all.

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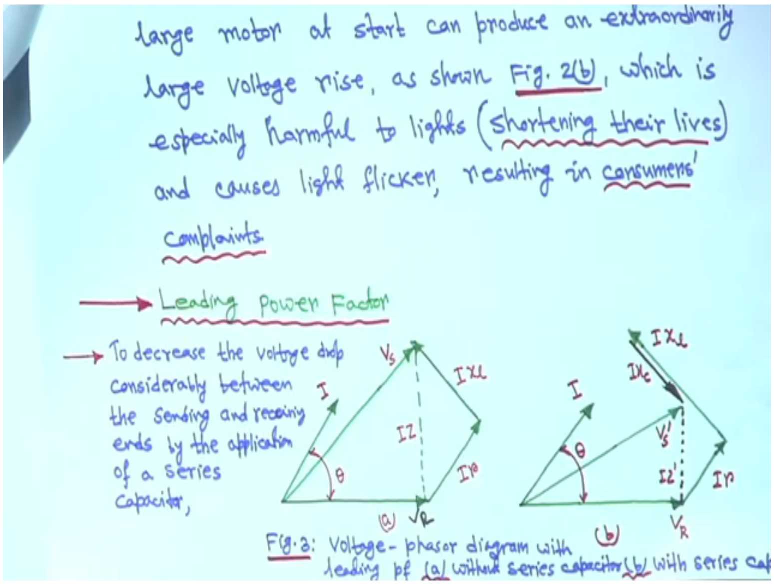


Because the lagging current your this current is lagging, this current is lagging because of the lagging current of the large motor a start. Because you know that motor starting current maybe 2.5 to 3 times; then it get a current from electrical machine you have studied that right. An extraordinary large voltage rise as shown in figure 2 b right, this is figure 2 b.

So, in that case right which is especially harmful to the light shortening their lives and causes light flicker resulting in consumer complaints right. So, this consideration this these are certain consideration you have to your what you call you have to consider this because of the large current, this I r voltage drop which higher. That is why I compared to this on the it is not on the scale, but this I r and I x l minus x it will be higher. So, one has to be very causes about series capacitor right. So, this is certain drawback of the series capacitor right.

Then leading power factor case: So, when power factor is leading when power factor is this is your current phasor and this is your this is VR I forgot to mention this. This is VR right and this is your I r because current is leading. So, I r I x n and this is never 90 degree right because of my drawing it shows like this but not right. It may be anything right. So, and this is the your what you call that your leading power factor case. In that case there is a possibility that VS maybe depends on the current and line parameters; VS maybe less than or greater than VR also; either way it is true. VR also maybe greater than VS or less than VS either way it is true.

So, this is voltage diagram when the current is leading right and this is when compensation is there; suppose leading current condition when the compensation is there. So, this is I x l some part it is compensated I x c right and in that case this is your VS dash, this is VR, this is I r and this angle is theta. So, whenever you series capacitor this angle is not change actually right almost same but due to the series compensation the voltage VS dash has changed. So, because of that although it is showing VR also; you when you compute VR due to dash VR also will be different right. So, it is not it these are not same right.

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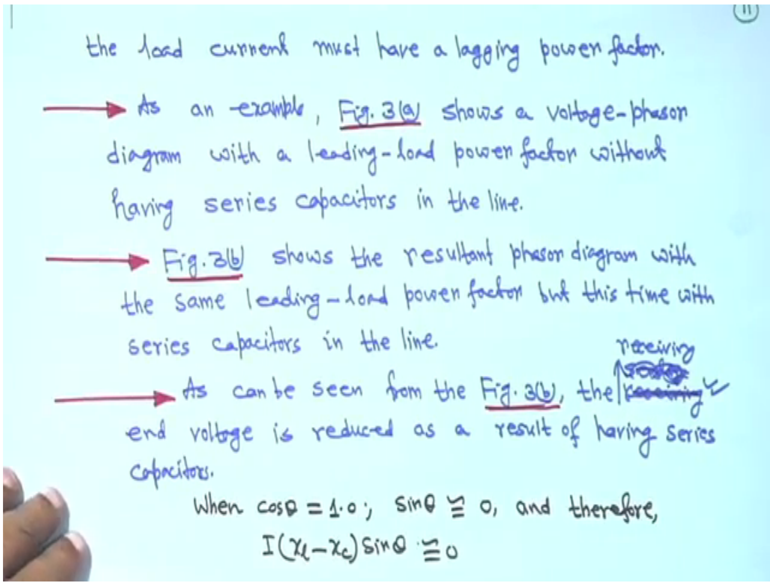


So, that means, the load current your what you call, something I have a written here for you; something I have explain only right. Therefore, that to decrease the voltage drop considerably between the sending end and receiving ends by the application of a series capacitor right. The load current must have a lagging power factor right; lagging power factor is preferable right. As an example figure 3a shows a I showed you all this figure and explained also; voltage diagram with a leading load power factor without having series capacitor in the line and figure 3 will also I showed you right; the resultant phasor diagram with the same leading load power factor but this time with series capacitor in the line right. So, as can be seen from the figure 3b just a this figure I showed you just this figure your this figure this is figure 3b; this is figure 3 b right. So, if you assume that unity power factor case say a cos theta is equal to 1; that is unity power factor case. Then I and VR in the same they are in same phase VR and I; theta is zero right.

In that case that sin theta is approximately 0 and therefore, I into x l minus x c sin theta is equal to 0 right. In that case what will happen that this term actually is becoming 0; I into this term is becoming 0; in equation 3. .

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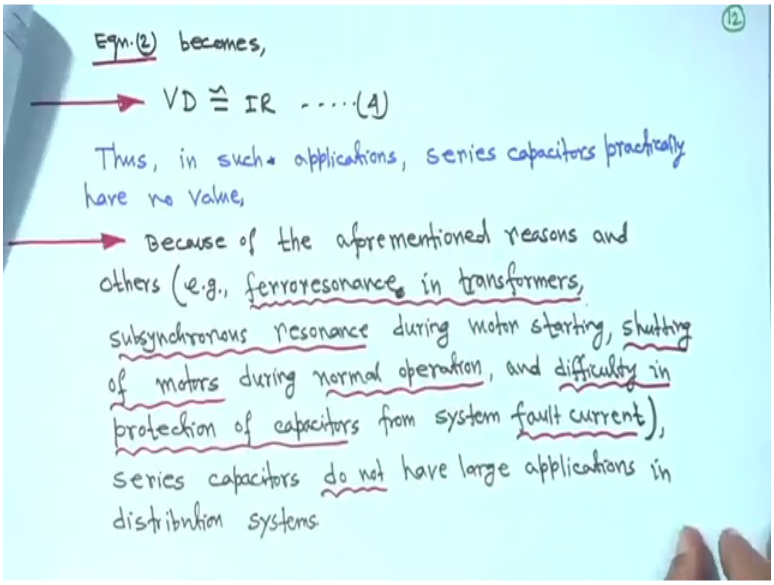


So, in that case what will happen that your VD voltage drop will be simply I into R right because that the second term is vanish. So, this is (Refer Time: 08:36) in such application series capacitors practically have no value because your x c is equal to your x l and your VD a that sorry unity power factor case right not x c is equal x l; that unity power factor case, voltage drop is simply I R. So, series capacitor it has no value right.

So, because of the afore mentioned reasons and others. For examples ferroresonance in transformers, subsynchronous resonance is the more pronounced right during motor starting, shutting of motors during normal operation, and difficulty in protection of capacitors; series capacitor of course from system fault current; series capacitors do not have large application in distribution system.

So, there is not much application for the series capacitor in the distribution system right. So, these are the certain things about the series capacitor and after that we will go for your what you call the shunt capacitor right. So, next is your what you call the shunt capacitor.

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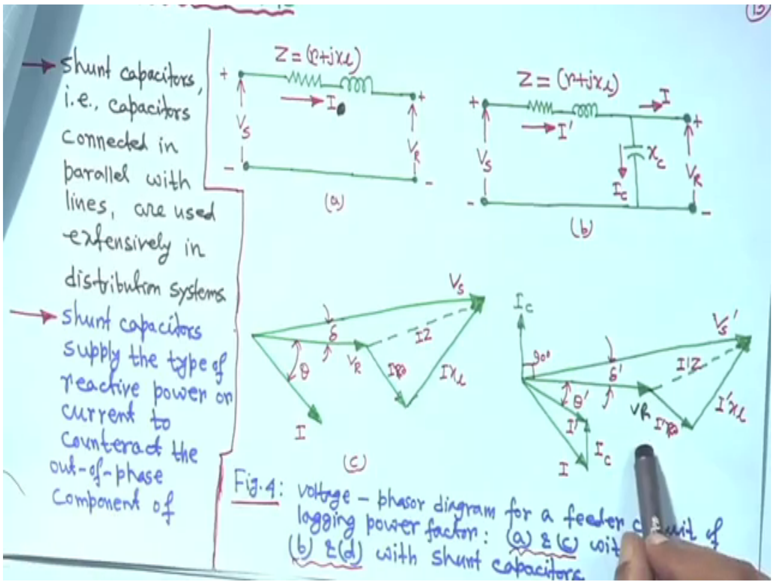


So, in the case of shunt capacitor case this is the diagram without your what you call without shunt capacitor. Impedance is Z is equal to r plus jxl and Z is equal to here r plus jxl but at the receiving end say if shunt capacitor is connected current is I c and it is reactance is x c and this is the same phasor diagram as in the case of without anything right. So, current is lagging we have taken; current is lagging we have taken. All the right of it is here but I am explaining that right and this is your what you call that your that is your phasor; this phasor diagram.

This phasor diagram corresponding to this and this phasor diagram corresponding to this. The it is actually capacitor it is leading current and this voltage I have missed it. This is actually VR; this voltage is VR and leading current it is I c right. It is I c; this angle is 90 degree and because of that right suppose this angle is delta dash because as you have your what you call from this diagram you can make out the current here I dash is equal to I c plus the I; current which is going to the load it is at the receiving end side right. So, this is your I dash R because here it is I dash into r this side right plus I dash x l this one I dash x l right and this is in this case your this current is I c.

So, this current is I that is this current without any capacitor. Now capacitance because this I c current; it is by your what you call, it is making 90 degree angle with this one. So, phasor from this side will move like this. So, this is I c. So finally, it is coming to I dash right. So, because your I dash is equal to I; I dash is equal to I plus I c. So, if you come to there I dash is equal to I plus I c right. Here if you apply Kirchhoff's first law here, I dash will be your I plus I c. If you look at this phasor diagram that I is equal to your I dash is equal to sorry I dash is equal to I plus I c.

So that means, this effective that current magnitude I dash current actually is decreasing; current is decreasing; that means, here power factor angle was theta, now it is theta dash because of series capacitor. That means theta dash is getting decrease; that means, power factor actually is improved right. Therefore, this is your I dash R; this is I dash x l and this is I dash Z, so voltage drop right. So, that is why if you put shunt capacitor that your what you call that it improves the power factor.

Whereas, series capacitor actually there is no change of theta but in the case of shunt capacitor there is a change of theta right. So, if current decrease that means, current decreases, current decreases means the loss I square R with without your this thing what you call this is actually your what you call I sorry not I s right. So, we without we here it was current I. So, if you add I square R, so I is magnitude of I greater than this one. So, power loss is high, but here from this diagram we can make out I dash; if you take it is magnitude I dash actually compared to this I is decreasing.

So, here power loss will be magnitude I dash square into R. So, power loss will decrease. So, purpose main purpose of the series capacitor is the reduce the power loss in the network shunt capacitor right; main purpose of the shunt capacitor. So, that is why this is the phasor diagram. Hope this is understandable, this is understandable right. So, all this things write up is here.

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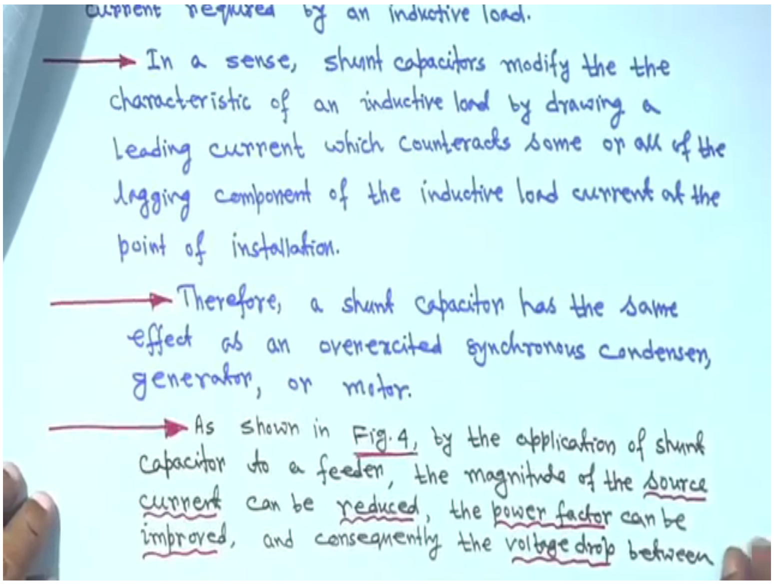


So, in a sense shunt capacitor modify the characteristic of an inductive load by drawing a leading current. Everything I told you right, everything I have written here also which counteracts some of; all of the lagging component of the inductive load current at the point of installation right. So, actually if you look at the diagram this I dash this capacitor is connected right. So, as this which is drawing leading current, it is actually compensating some of the reactive load at the your what you call at the receiving end. .

So, therefore, this shunt capacitor has the same effect as an overexcited synchronous condenser, generator or motor right; effect is similar. But as shown in figure 4 by the application of shunt capacitor to a feeder, the magnitude of the source current can be reduced I told you that this is the source current. This magnitude of the source current actually is reduced this is I dash now. If you look at the phasor diagram this I dash is less than I right and the power factor can be improved because earlier that angle was higher now angle is decreed.

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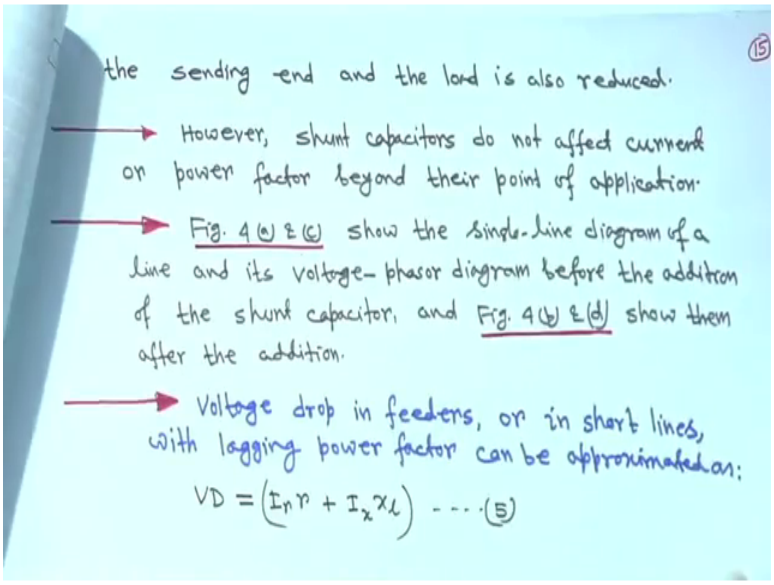


So, naturally cos theta will increase right; cos theta dash rather will increase right and the power factor and consequently the voltage drop between the sending and receiving a load is also reduced because of your what you call because of this capacitor, the voltage drop will also reduce because this current actually getting decrease. So, I dash into r plus jxl will decrease. Therefore, at this point if you this point this point remains same. So, at this point voltage also will improve; receiving an voltage will improve; do not much, but it will improve right.

So; so however, shunt capacitor do not effect current or power factor beyond their point of application. This I have I have explained your previously in that your what you call in that your yes previous class that wherever your capacitor is connected and beyond that point it will not be affected; only little bit effect will be there due to the improvement of the voltage right. And figure 4 a and c. So, the single line diagram or line and voltage to the diagram and before the addition of the shunt capacitor and figure 4 b and d shows them after the this thing. I mean this one; this is figure 4; this a and c; this is b and d. All I have all I have explained right.

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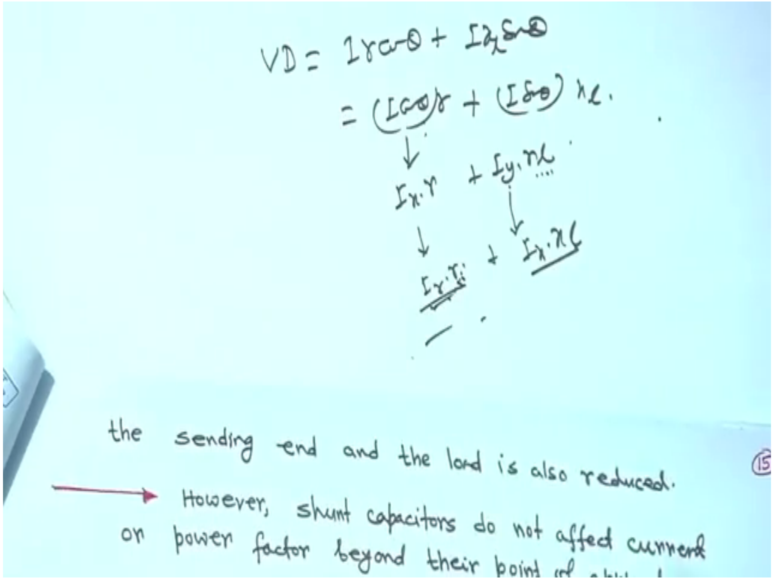


So, voltage drop in feeders or in the short lines with lagging power factor can be approximated at I r into r into I x into x l; that why you are writing this that we have seen know that voltage drop is equal to I r cos theta plus I x sin theta. Actually it is actually I cos theta into r that is your and this one is that is I x component and I sin it is x l right it is x l; I sin theta into x l right. This is actually x component.

So, you can write this is I x into r and this is y x is component; this is we can make I y into x l right. So, but anyway this is what you what this is what I am writing this one. Instead of this real component instead of x component xx is components, what I have writing? This is I r into r that is your resistive that is that r into r that drop related to the register resistive part. So, I r into r as it is related to reactance part, so instead of y I am writing I x into x l right; this way I am writing.

So, here your voltage drop that is why this equation from this only we are writing that it is I r that is a real part, your resistive part voltage drop I r into r and this is the inductive part that is why I x into x l. Actually this is your xx is component and this I x is y x is component from the current. So, this is equation 5 right but for easy remembering I r into r plus I x into x l right; where I r is equal to I cos theta and I x is equal to I sin theta right.

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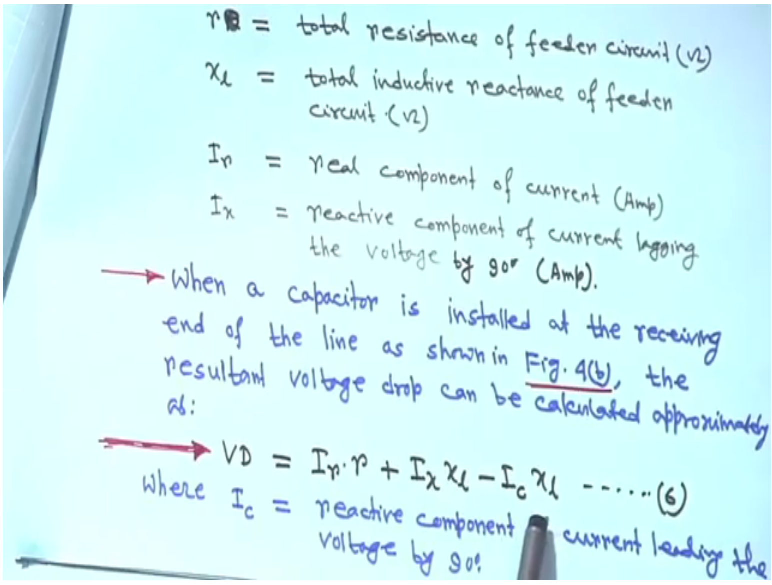


So, r is the total resistance of the feeder that is in ohm; x l is equal to total inductive reactance of the feeder it is in ohm. So, I r is equal to real component of current in amperes and I x is equal to the reactive component of current lagging the voltage by 90 degree it is ampere right. When a capacitor is installed at the receiving end line as shown in figure b, the resultant voltage drop can be calculated approximately.

This is very simple. It will be VD is equal to I r into I r; you know everything now plus I x into x l minus I c into x l. That is this figure several times I have told from this figure also you can write that V s dash cos sin delta dash is equal to your I dash r right; your what you call cos theta and I dash x l sin theta. So, and of course, your what you call minus your I c x l will come because this capacitive current is there. Because I dash is equal to basically it is I plus your, what you call, I dash is equal to I plus I c right. So, because of this just a every everything I have told. This I dash if you take this I dash x l; actually I dash is equal to your I plus your what you call I c right.

So, in that case if you just little bit if you simplify of your own you will see that voltage drop will be I r into r plus I x into x l minus I c into x l right. This is actually equation 6; where I c is the reactive component of current leading the voltage by ninety degree right. So, whenever you consider I c in this phasor diagram and simplification, please see that current is leading; that means, that that angle has to be considered by 90 degree right.

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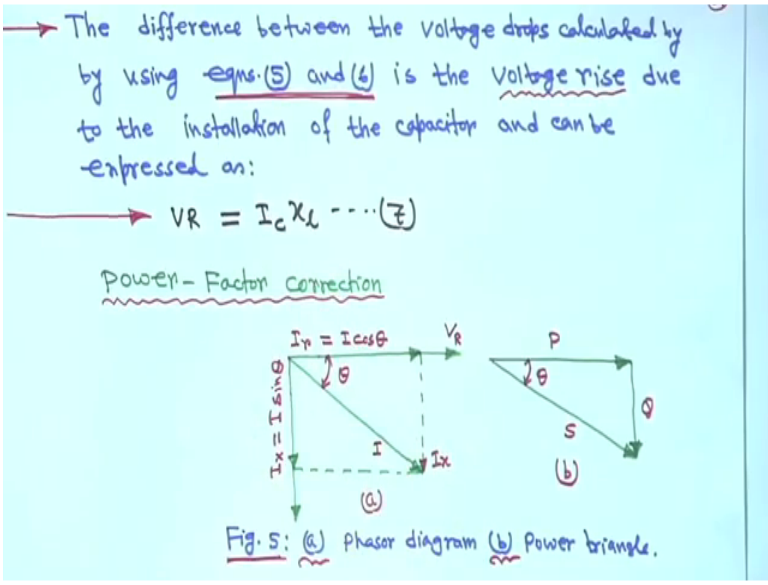


So, in that case your difference between the voltage drop calculated by using equation 5 and 6; that is basically the voltage rise will be I c into x l. Because if this much if this much voltage I mean voltage drop this much is less means this much actually voltage rise right in the other way. Voltage drop is less means this voltage this much is the I c into x l is the voltage rise right. So, there for your power factor this is your I cos theta, this is the I x sin theta this is the I and this is power triangle; this is p and this is q; this is equation 7 right. Therefore, this is a phasor diagram and this is your power triangle. That means I mean; that means, that in that capacitor application I was telling you something.

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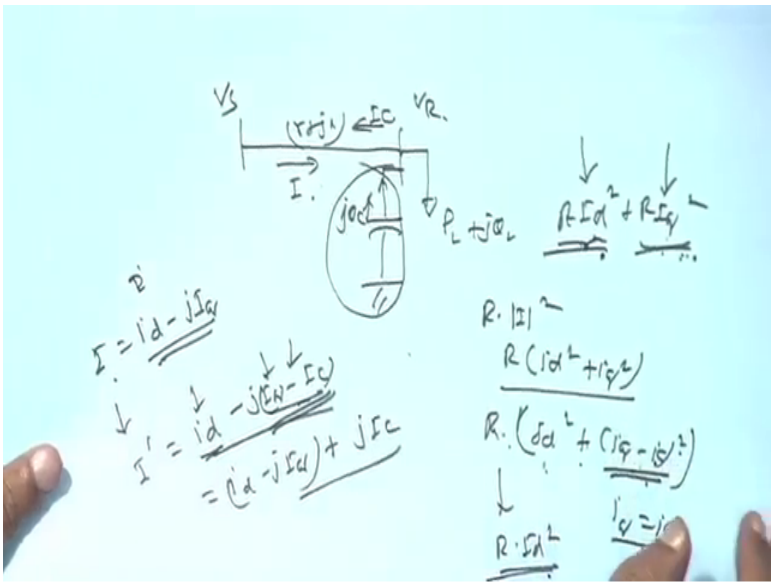

Suppose if you take for example, suppose this is your sending end node and this is your receiving end node right and you have a load suppose it is P L plus j Q L and same diagram we have taken. Suppose you have connected capacitor, this is say j Q L and this is your sending end node; this is your receiving end node. This line has impedance r plus j x; this line has impedance r plus j right. Because of this that initially I mean suppose current was suppose it was a lagging current; for example, it is a lagging current.

For your understanding, suppose the current is I is equal to say id minus j i or I q right. Previously while explaining I took id plus j I q that is for simply that is such just for purpose of understanding because of the lagging current we can take id minus j I q right. So, this current is flowing this direction this I is flowing this is this direction. But because of this capacitor know this capacitor from the connecting node to the source the current flows.

So, this way that current will flow because current is leading this way it will flow; that means, as soon as you the put the capacitor that your this is this current say without capacitor shunt capacitor, when the shunt capacitor was not there without shunt capacitor. But as you put it here then I dash actually will be id minus j I q minus I c because it is the; that means, this much of reduction right. So, this is actually; that means, this is actually id minus j I q right; plus your j I c this way we can write. So, in the actually this part is getting decreased but this part almost not change but because of the voltage improvement there will be if you go through computer simulation you will find there will be slight change but for the our understanding say this part remain constant; this part also remain constant with capacitor also.

So, because of this part is decreasing; that means, before that look before that power loss was R into I square right; that means, R into id square plus I q square right because modulus of this is your root over id square plus I q square. Therefore it is id square plus I q square. As soon as you put the capacitor this part, the lost will be actually in the bracket I can write id square plus i q minus i c square right.

Because this part is getting decrease right; this part is getting decrease that is why power loss will reduced. But listen one thing that theoretically you can make i q is equal to i c; that means, this part will be 0; that means, R into I d square; this loss will remain in the circuit. That is the inherent property of any circuit common circuit right; that means, you cannot make power loss in a network completely 0; it is impossible right. So, just taking a simple example I want to show that this part this part that is your if you take mod of I, it is root over id square plus I q square. If you take this one without capacitor; if you put capacitor it is R into id square plus i q minus i c square.

But theoretically you can make i q is equal to i c. If you make i q greater than i c does not matter. It is square some component will be added here, but ideal condition i q equal i c means this term will vanish; that means, if it is so, then loss will be R Id square; that mean loss in any network cannot be made to 0. This part of the power loss will remain in any electrical circuit; that is the inherent property of any circuit; you cannot make it to 0.

Sometimes book may not be given ah, but sometimes some time re such researching via found that this loss was actually this loss actually can be made it I Id square plus R I q square. This is R id square, this is R I q square; this sometimes we can call. This the direct x is component of the power loss and this is your quad nature x is component of the power loss. So, theoretically this quad nature x is component; it can be made it to 0 right because of i q is equal to i c.

Say it is possible, but this you cannot touch right. It will remain in the circuit right. So, unless and until your load is 0 this id cannot be zero right. So, anyway that is not the case. So, this R Id square will remain in the circuit any circuit. This cannot minimized; this will be I mean theoretically that R id square actually minimum power loss in the network. I hope you have understood this right this is very interesting, but I thought I should tell you right. So, this is actually your what you call that your that is that voltage I mean as far as voltage drop deduction is there, so this much actually is the voltage rise right and this is your power triangle and angle of course, is theta right.

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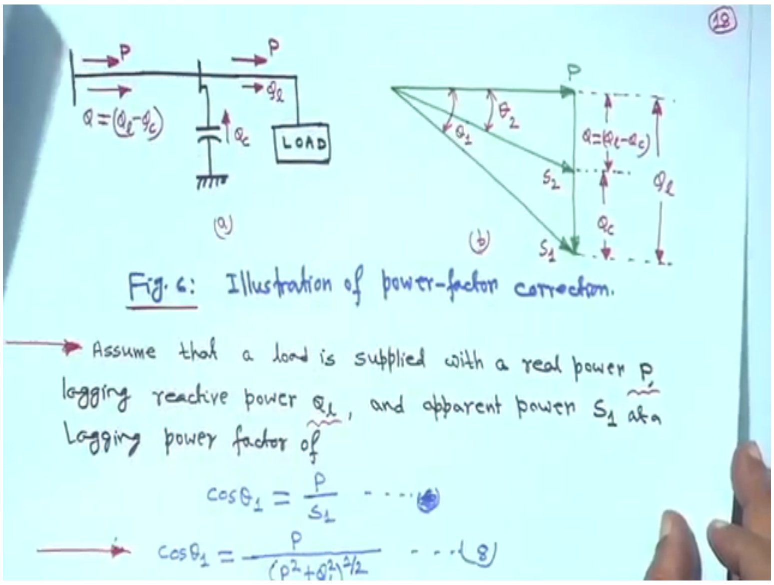


So, now suppose you have this is your sending end and this is your receiving end right and your this is your what you call that shunt capacitor is connected Q c; j I have not shown here every time, but understandable and this is the Q load right. Now, without capacitor when this is not there; if you draw the power triangle, so this is this theta 1 actually is the angle without using shunt capacitor right without using shunt capacitor. So, at that time that when it is not there, when it is not there right; if it is not there then at that time Q is equal to Q l right.

So, in that case your assuming that there is no loss in the network assuming that there is no loss in the network. So, this is your P and this is your what you call that Q; Q is equal to Q l, this is actually Q l; this from here to here it is Q l right. So, in that suppose for the sake of think that suppose this is your point O say right. So, this is say point A right. So, at that time this I mean shunt capacitor is not there, it is Q is equal to Q l. So, in that case angle is theta 1; that is without shunt capacitor, loss is neglected loss is not there.

Now, suppose this Q c is connected; that means, as soon as this Q c is connected; that means, from that connecting node from this node that actually that capacitive current will flow from the connecting node towards the source. This is actually this is actually source right; this is actually source. So that means, effective; that means, effective Q which will come from the grid or from the source; this side is source right it will be Q l minus Q c. So, in that case your what you call; that means, it will draw less reactive power from the source or from the grid because this Q c actually as it is drawing less means actually effectively that your cell what you call that load reactive power is getting compensated. Basically, it will become Q l minus Q c.

So, that is why in the second it is S 1 is the apparent power initially that arise. So, initially S 1 is equal to when nothing is there is equal to P square plus Q square; when your Q or your Q l square rather right but as soon as you put some amount of capacitor Q c right. So, at that time Q will be Q l minus Q c. So, with these sides say it is A, B, C say this is say this is B right. Then at the time PB will be Q is equal to Q l minus Q c; that means, your apparent power drawing from the substation or drawing from the source right will decrease this S 2 will at the time P plus root over your Q l minus Q c square. That means, because this Q c is coming from the shunt capacitor all the total is Q l right; without considering any loss and this is the power triangle.

Now, this is the simple thing right. Power actually loss is not considered here just for the purpose of outstanding. But just I showed you all the losses; same thing. This diagram this diagram is same; if loss is there then I told you what is the your what you call, what is the your effect right. So, in that case assume that a load is supplied with a real power P. So, this load has a real power P and reactive load is Q l. So, it is P plus j Q l without any capacitor, shunt capacitor right and lagging power for this Q l and the apparent power is S 1 right.

And at a lagging power, so cos theta 1 from this some from this triangle actually cos theta 1 will be basically OP upon your OA; that is your P upon S 1; P upon S 1; that is P upon root over P square plus Q l square right because without anything it is load was P plus j Q l. So, it will be root over P squared plus Q l square. That is P square plus Q l squared to the power half. This is actually equation 8 right. .

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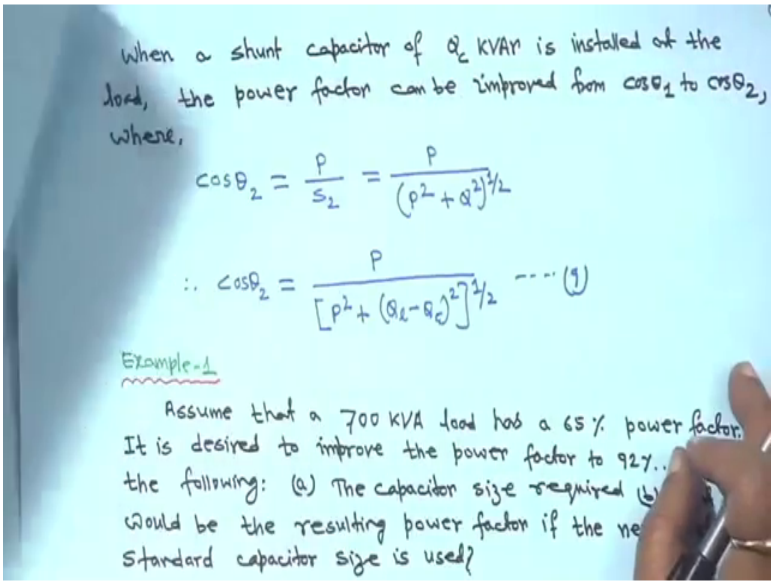


Now, when a shunt capacitor suppose Q c kilowatt is installed at the load; suppose capacitor installed at the load, the power factor can be improved from cos theta 1 to cos theta 2 because angle getting decrease, so cos theta will increase; so this is cos theta 2. In that case, cos theta 2 will be OP upon you are your OB right. So, it is actually; that means, P upon S 2; that is P; this OP is P and this is OB this S 2, so P upon S 2. So, basically it is P upon root over P square plus Q square; that is P square plus Q square to the power half right.

So, Q is equal to this 1 Q l minus Q c this much is drawing from the your source. Therefore, it will be earlier it was earlier Q is equal to Q l. Earlier Q is equal to Q l that is why we wrote square plus Q l square because when your what you call when Q c was not there it was 0; Q is equal to Q l. So, not writing again and again directly write in P square plus Q l square to the power half right yeah. Now when it is there the cos theta will be P upon S 2. So, P upon P square plus Q square to the power half that is under root of that right or cos theta will be P upon P square plus Q l minus Q c square to the power half right.

So; that means, whenever you put shunt capacitor right, it actually it actually observe the, your what you call that what you call it reduce the reactive power drown from the source. So, such that it improves the power factor of the your what you call that (Refer Time: 29:47) your if it is substation then it will improve the power factor at substation. At the same time that you will find that load is there. So, for example, any industry all the induction motor load you will find the shunt capacitors are connected across that across that power factor can be improved. Because that if you operate at less power factor then tariff charge will be higher for industrial people because it will drop more kVA because that tariff is sometime two parts; sometime three parts tariff right; with some kilowatt hour; kilo per hour and at the same time because of the peak kVA demand.

So, if that is why they connect the shunt capacitor across the, suppose a motor load such that it will draw less kVA from the network. Otherwise your for your kVA demand charge also they put they charge it; so three part tariff right. That is why you will find industry the shunt capacitors are always there.

Thank you we will back.