Operation and Planning of Power Distribution Systems
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Lecture - 21
Reactive Power compensation of Distribution Systems with Shunt Capacitors

This is a new module that is module 5, in which I will basically discuss this Reactive Power Compensation of Power Distribution Networks or Power Distribution Systems with Shunt Capacitors ok.

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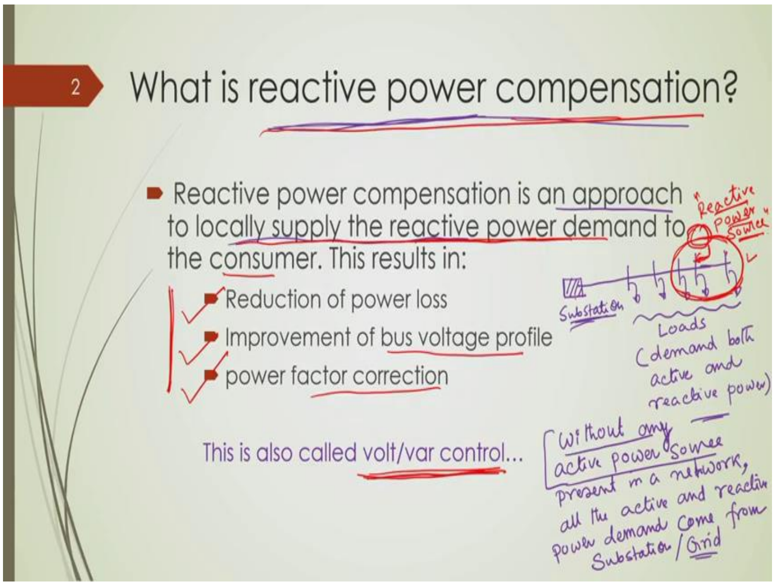

So, before I move forward let me talk about, what is reactive power compensation ok. So, reactive power compensation is another important paradigm in power system research and we also have many papers or many articles published on the same topic which is applicable in power distribution system as well as in power transmission system. Now the basic question is before I move, what is reactive power compensation? Ok.

So, this is although not a standard definition, but this gives you an idea that what do you mean by reactive power compensation. Now, reactive power you can understand I hope that it is a form of you know power which exists for any type of practical load, it is eventually required, but it does not provide us a any useful work ok.

Now, reactive power compensation is an approach to locally supply this reactive power demand to the consumer or to a particular load. Now, why we are intending to provide this reactive power demand? In fact, in my last lecture in the last module where I discussed this forward backward sweep load flow approach for solving this power flow problem of radial distribution networks you have seen that we model this load demand in terms of the active power demand as well as reactive power demand.

Active power demand means it is the real power demand which the load consumes in order to convert it to some useful work. And reactive power demand although it exists, but it does not provide any useful work to us, but and you and since any sort of practical device any electrical appliance which demands this reactive power. A utility needs to provide that reactive power to the customer.

So, mostly all the consumers they have lagging power of load or inductive type of this load, and this inductive load consumes both active and reactive power ok. And who will provide this reactive power. So, utility has to provide this reactive power. Now, suppose I have a substation at this point, here I have substation and this substation is connected to a feeder which is having a number of loading points or load nodes each of the loading points as we have seen we have certain number of loads connected.

So, these are the loads. So, this load demands both active and reactive power. Now who will supply this active and reactive power, if there is no source connected in between any point between substation to this furthest load of course, this both active power and reactive power demand for all the loads are supplied by or are fulfilled by the substation ok. So, without any active power source present in a network, all the active and reactive power demand comes from substation or grid ok.

And you know this, the power distribution networks without active power source we called that it is a passive network ok. So, presently till today most of our distribution networks are of passive, they do not have any active power source in between ok. So, all the loads who demand this active and reactive power, this demand is made by the grid and the junction point of the grid that is the substation; and now we assume that all this demand is made by the substation ok. So, that is what this meaning.

Now, reactive power compensator is to locate or is to place a source of reactive power in between any point of a substation to the furthest load. So, suppose I provide a reactive power source. So, this one is reactive power source. Now what do you mean by reactive power source? Means it can provide reactive power. So, if we place this reactive power source at this point then I will show you mathematically that if you place a reactive power source at any point in between the substation and any of the loads.

Then that source will eventually provide or it will eventually meet the reactive power demand of some of this neighboring loads depending upon the capacity of the reactive power source and depending upon the demand of the reactive power source ok. So, to supply this reactive power locally by using any reactive power source is called as reactive power compensation ok.

So, is it clear? So, this is the informal way to understand that how what is reactive power compensation. So, reactive power compensation is an approach to locally supply this reactive power demand to the consumer or load ok. Now why we do this? When we use an approach or when we place something it should have some merit ok.

So, here this local source is supplying this reactive power demand by using a reactive power source placing in between this at any point of the feeder will significantly reduce the power loss of the network why it will do so, I will come to that. It will improve the bus voltage profile or node voltage profile, and it will also use as a power factor correction ok. I will discuss all these three points elaborately in my further lecture, but these are the basic points of this reactive power compensation one needs to understand.

And also sometimes this the way we define this reactive power compensation is useful for any type of passive distribution network and it sometimes called as volt var control if it is used to improve this network voltage then it also called as volt var control ok. And of course, this reactive power source placement needs some additional investment to utility and also it will cause certain problem because you know capacitor switching will cause some sort of transients some serious transients.

So, keeping all this in mind this placement of capacitor will act as an important aspect or important approach to reduce this power loss or to improve this voltage profile and that is why we do it. And in fact, sometimes there are many approaches on reactive power compensation and sometimes in some of the approaches you will see they do this cost benefit analysis that whatever investment you require to provide this reactive power compensation should also suffice that whatever benefit you are getting out of it ok.

So, those things we will study in one of my slides in detail ok. So, as a whole this reactive power compensation is an approach to locally support this reactive power demand by placing a reactive power source at some point of this network ok. So, these things you can understand.

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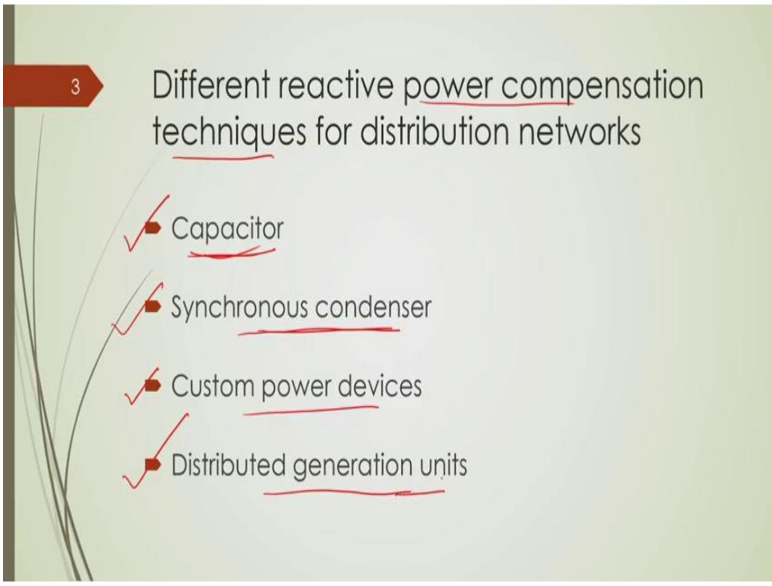

Now, what are the techniques or approaches available for reactive power compensation in a typical distribution networks? One is capacitor as you know capacitor is a source of reactive power, why we call it a source of reactive power because most of our loads are of inductive and you know that inductive load they also exchange some reactive power and capacitor also exchange the reactive power.

And their exchanges occur in just opposite to each other means when capacitor draws reactive power from the source the inductor provides the reactive power. So, if you place a capacitor near to an inductive load. So, both will exchange the reactive power and thereby the load will need not to draw this reactive power from the grid or from the substation that is what the main point I was trying to establish ok. So, capacitor is one of the sources of reactive power. So, it is used for reactive power compensation.

Synchronous condenser ok or synchronous motor under specific type of operation it will also provide this reactive power. Similarly, there are some power electronic based devices which are usually used for reactive power compensation for distribution networks they are called custom power devices.

And also the distributor generation units can provide reactive power provided that its inverter is capable to exchange this reactive power ok. Some of the distributor generation these things I will discuss in detail in 7th module, but this distributed generation some specific types, there are many distributed generation units, but some specific units they can provide reactive power ok.

Now, here in this particular module I will discuss this reactive power compensation with capacitor placement or in to be more precise we will discuss the reactive power compensation with shunt capacitor placement ok.

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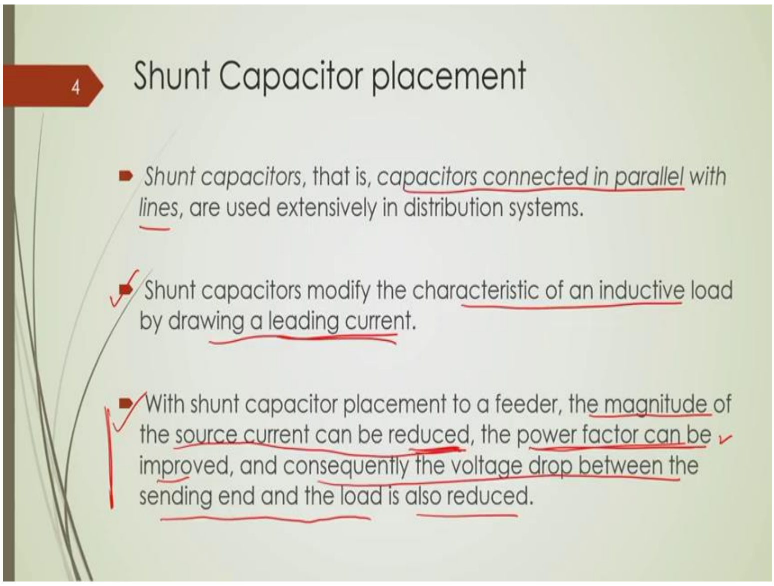

Shunt capacitor means capacitor connected in parallel with the line ok. So, as I have shown you here, for this particular load who demands active and reactive power we keep a capacitor in parallel to this load ok. And this capacitor will supply this reactive power to that particular load depending upon its capacity.

So, if capacitor capacity is higher than apart from meeting that reactive power demand of that particular load, it will also provide reactive part to the neighboring loads as I have mentioned ok. Now, as I said the shunt capacitors modify this characteristic of inductive load by drawing a leading current ok.

So, leading lagging current, these are confusing, but one you can understand that whatever this inductive load operation we have exactly opposite operation exactly complement operation we will get by using capacitors ok. Now, with shunt capacitor placement we have feeder, the magnitude of source current can be reduced, this I will in fact discuss with an example ok, why it is so?

And power factor can be improved again I will discuss with an example that how it is happening and consequently the voltage drop between the sending and receiving inside or sending or load inside is also reduced. So, all this I will explain with an example in one of my slides after few minutes of today’s lecture ok.

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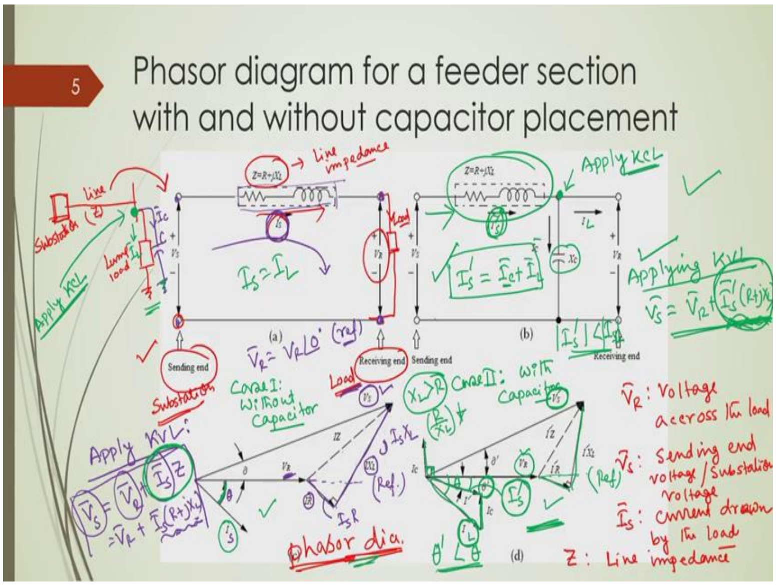

Now this is an example of a load connected to a particular feeder. You assume that here we have a substation, here we have substation and here we have a lump load, here we have a lump load which demands both active and reactive power ok and this is the line distribution line and this is my substation or source ok. So, this is similar to a 2 bus system ok.

Now, if we represent this as an equivalent circuit, then this circuit will look like this. So, this part is this left hand side is sending node where we have this substation located and this extreme right hand side is the receiving end side where we have load connected. In fact, this is not open, but we have a load connected there. So, this is our load ok.

Now, this is basically line impedance this Z that is line impedance ok, and this is the same line impedance here ok, and we assume that this load is drawing a current I S from the substation. And at the load end this voltage across this load is V R. So, here I write V R is voltage across the load, V S sending end voltage or substation voltage ok.

And I S is current drawn by the load ok. So, this load is drawing this current I S ok, and Z is basically line impedance ok. So, this is my substation end and this is my load end at any instant of time if we consider the polarity of the voltage is negative positive there and the polarity of load voltage is negative positive as shown in the figure, then the direction of the current will be from the sending end side to the receiving end side ok.

Now, in order to draw the Phasor diagram for this particular you know condition. So, in order to draw the phasor diagram what we need as I said. So, we as an electrical power engineer, represent any circuit in a form of equivalent circuit and we draw phasor diagram from this equivalent circuit. Now, how do we draw this phasor diagram? So, in order to draw this phasor diagram we need algebraic expression for this voltage and current ok.

So, in order to find this algebraic expression let us apply KVL across this loop. So, if we apply KVL Kirchhoff's voltage law then what we will get? We will get this sending end voltage V S is equal to the receiving end voltage V R plus this line drop. So, this line drop is represented by I S multiplied by Z ok, or alternatively you can find out this is sending end voltage. If you subtract this voltage drop due to this line impedance then whatever voltage you will be getting that will be the voltage at the receiving end line where our load is connected ok.

Now, this Z I can write it as a V R plus I S multiplied by R plus j X L, where R is basically line resistance and X L is basically line reactance. So, this algebraic equation will help us to draw the phasor diagram draw the phasor diagram ok. So, this algebraic expression will help us to draw the phasor diagram. So, first in order to draw the phasor diagram we have to keep some parameter as a reference.

So, here we have two voltage parameters one is V S another is V R and also we have this current, these are the phasor quantities we know, Z is not Z is constant ok, Z does not depend upon the time ok. So, considering this receiving end side or load end voltage as a reference, we will draw this phasor diagram here. So, we assume this V R as a reference so; that means, V R is equal to V R phasor is equal to V R at an angle 0 because it is considered as a reference ok.

Now, corresponding to that where would be this current I S located. So, since this load is of inductive. So, I S will lag by some angle theta with respect to this V R or where V R is your load voltage. So, I S will be that and now when we get this I S, I need to find out this line drop which is having two components which one is I S multiplied by R, another is I S multiplied by j X L ok.

And as you know I S multiplied by R so, this I will be in phase of this I S ok. So, this is drawn in phase, this is the drop which represents I S multiplied by R ok. And j I S X L it will lead 90 degree with respect to this I S because we have this operator J ok. So, this is drop of j I S X L ok. So, this is the drop ok. So, if you add these two drops with this receiving end side voltage then whatever phasor we will get that is the sending end side voltage or substation voltage ok. So, this is the phasor diagram that we know, I mean you have seen this previously also ok.

Now, you see if we put a capacitor here in parallel to this load if we put a capacitor here in parallel to this load ,where this capacitor will also draw some current I C ok some current I C; and then what would be the revision or modification of the phasor diagram ok. So, without capacitor this phasor diagram is drawn. So, this is applicable for case 1 that is without capacitor.

Now, we put a capacitor here in parallel to this load, then we will be having some revision of this scenario, then we will also draw this phasor diagram with capacitor. So, this is let us say case 2 ok. Now when we have this capacitor connected to the receiving end side or at the load end which also draws some current ok. And capacitor current is a leading current leading current means its capacitor draw a current which leads its voltage by 90 degree ok.

We assume that capacitor is ideal capacitor ok capacitor is ideal capacitor. So, if it is so, then if we put KCL at this particular node if we apply KCL then what we will get? We will get there are two components of currents one is I S and one is I L where I L is the current drawn by the load. So, without capacitor this I L was equal to this line current that is I S, but now we have this I S changed to some I that is I dash is shown over here and this I dash is obtained by applying KCL at this point.

Because with when we connect a capacitor in parallel to this load, this will be the equivalent circuit ok; and this is the capacitor which is drawing this current I C ok. Now if we apply KCL at this point what we will get is current, let us represent I S dash. So, I S dash is equal to this I C plus this current drawn by this load. Let us represent it I L ok. So, this is I C plus I L ok.

So, now again in order to draw this phasor diagram what we will call we consider this V R as a reference and only more modification of this you know voltage expression is applying KVL what we will get? Now this V S will be equal to V R plus I S multiplied by R plus j X L this is the line drop which depends upon this current I S dash and this impedance that is Z. So, since impedance remains constant. So, it varies with this current I S dash ok.

Now, we have two equations one is this, another is this and we have to draw the phasor diagram with these two expression or two algebraic equation. So, what we can do? This is my receiving end side voltage. we consider it as a reference and this is the current that is basically the load current that is I L, and let us consider that it is lagging with respect to this voltage across the load that is V R at an angle theta ok at an angle theta.

Now, as we know this is not this I L is not this current which is drawn by the load from the substation; now current drawn from the substation is changed to I S dash now, how to get this I S from this expression from this KCL equation. So, I S dash is equal to I C plus I L. Now, how do we know what is I C. So, as we know that this I C is basically that current which will lead voltage at 90 degree assuming that capacitor is ideal.

So, this I C will lead 90 degree with respect to the voltage across this load or voltage across this capacitor. Now if we add this I L and I C whatever you will get that is basically this is basically I S dash ok. Now once you get I S dash you again add these two drops one is I S dash multiplied by R which is in phase drop, another is quadrature drop due to this line resistance and reactance respectively.

So, once you add these two whatever we will get that will be our V S or new V S ok V S or V S dash whatever you can call ok. Now, what is the difference between this phasor diagram and that phasor diagram? You can see the difference from this phasor diagram here is that of course, this angle which is between this current line current and the receiving end or load end voltage would be different; previously it was theta now it becomes theta dash. And of course, this theta dash is lower than theta; theta dash is lower than theta.

So, what is that you know implication of theta dash? So, it is basically representing this power factor angle net power factor angle of the load ok, which is changed from theta to theta dash. So, since theta dash is lower than theta. So, power factor is also improved ok, because higher power factor is preferable to us why it is. So, I will come to that ok.

So, theta dash since it is less than theta we can say the power factor is improved and that is why power factor is getting improved here ok. But apart from that you can see this was this current and before or load current before placement of the capacitor and this is the load current which is remain same because load is drawing the same current, but effective load current becomes I S dash now previously it was I S which was equal to I L.

Now, I S dash is not equal to I L; and if you look at this phasor diagram this magnitude wise this I S dash is lower than I S. So, why it is so, you know triangle will give you this justification that’s why this I S dash is lower than I L ok. So, since I S dash is lower than I L; lower than I L so, we can say that this current drawn by this load effective current drawn by this load is of reduced magnitude ok.

So, whatever current is drawn from the substation with this capacitor placement is of reduced magnitude ok and that is why since this voltage drop this voltage drop across this line impedance it is equal to this current multiplied by impedance where impedance is constant. So, if current is lower so overall this line drop will be lower ok. So, if voltage drop is lower then of course, that is a preferable situation that is a preferable situation.

So, whatever I mentioned in my previous slides all these three aspects you can see over here with the placement of the capacitor as we said that source current or current drawn from this. Source current means whatever the current is drawn from the substation that is getting reduced with this capacitor placement. And power factor is improved what do you mean by power factor improvement as I said the net angle between this current and this voltage that is V R and this I one is I S another is I S dash.

There is a difference of this angle one is theta another is theta dash and theta dash is lower than theta. That means that cos theta dash is higher than cos theta. So, with this capacitor placement, net power factor is getting improved ok. But apart from that we also have lower voltage drop. Why lower voltage drop? Because you have seen this voltage drop is basically depends upon this I S I multiplied by Z this I multiplied by this Z and Z remain constant because it is the line parameter once a line is built Z will remain constant.

Now, if this I is reduced I can be reduced. So, I Z drop will be also reduced. So, if I Z drop is reduced then voltage drop is reduced and if voltage drop is reduced then of course, it is beneficial for this customer because customer is getting a better voltage it is having a better voltage in terms of your substation voltage ok. So, this is one way to establish these three aspects that three advantages of this capacitor placement one is improvement of power factor, another is line current is reduced, another is your voltage drop is reduced.

Now, we have one important aspect which I am going to discuss here. If you look at this previous phasor diagram this and that this phasor diagram is drawn assuming that this X is X L line reactance is higher than R ok or X L is higher than R it means that this R by X L ratio is lower R by X L ratio is lower I can write over here.

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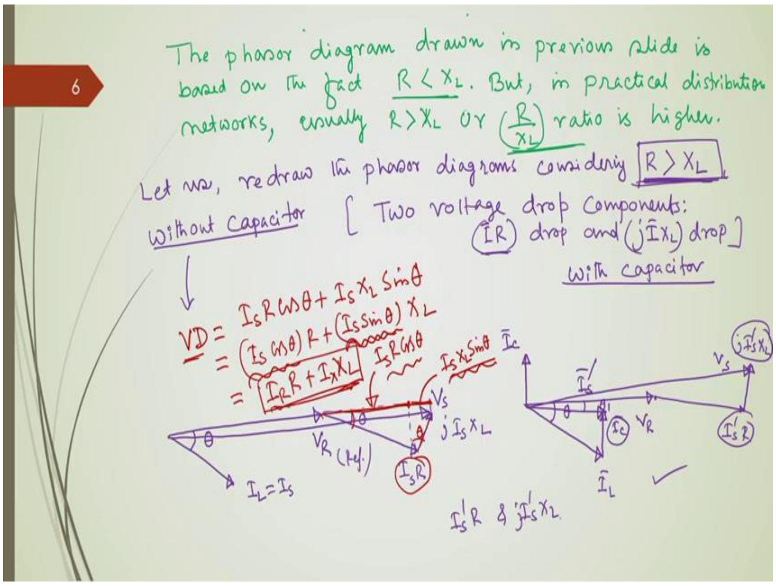

So, the phasor diagram drawn in previous slide is based on the fact R is lower than X L ok. But in practical distribution networks, but in practical distribution networks usually R is higher than X L or R by X L ratio is higher. So, this is already I discussed at the very beginning of the introductory lectures why it is so ok, in practical distribution network R by X L ratio is higher.

So, if it is so, then will this reactive power compensation applicable for distribution network or not ok. So, to establish that let me draw the phasor diagram. So, let us redraw the phasor diagram considering R is greater than X L; R is greater than X L ok. So, let us draw it now how will draw.

So, first draw this part and then I will go to that part ok. So, the first is without capacitor. So, let us draw without capacitor. So, without capacitor let us consider this V R as a reference ok. V R as a reference and that is basically that load current or current drawn by the load which is I L which is eventually equal to I S ok and it lags with an angle theta since as I said we consider this R greater than X L.

So, this you need to add here two drops one is I R drop one is we have two components of drop two voltage drop components that you know we have one is called I R drop I multiply I is phasor I R drop, another is j I X L drop ok. So, we have two voltage drop components. So, in order to put this I R drop considering that R is greater than X L since I R drop will be in phase with this I.

So, let me draw this in phase. So, this and this are in same phase. So, this is also theta and this is basically representing I S R and since X L is lower than this R or R is higher than X L. So, I can represent this X L like this. So, this is the drop I S X L then this would be the resultant of this will be our V S ok. So, that much of revision of the phasor diagram we will have; if we consider R is higher than X L ok. So, this is a case 1 that without capacitor. So, with capacitor what will happen with capacitor what will happen?

So, let us consider this is our V R now again my I L is lagging with respect to V R at an angle theta ok, but here. So, this is my I L, but it is not equal to I S or it is not equal to the current drawn from the substation ok because with capacitor we have two current components, one is current drawn by the capacitor, another is current drawn by the load here we have this load ok. So, this is the load current and this is the capacitor current ok.

So, we will also represent this capacitor current over here let us consider this is I C which is the capacitor current ok; and the net current will be the resultant of this I C and I L. So, let us draw this I C over here and this will be the I S dash ok this will be the I S dash ok. Now when we have this I S dash ok, we can add these two drop one is I S dash multiplied by R another is I S dash multiplied by j X L ok.

Now, this I S dash is power factor angle is changed to theta 1 or theta dash whatever you can call. So, this R I S dash R drop which will be in phase of with this. So, this is I S dash R ok or you can bit extend to have a similarity with this previous figure and then we will be having this much of j I S dash X L drop and this will be our V S this will be our V S. Now this will be the revision this will be the revision with this capacitor placement with this capacitor placement and eventually you can see this line current is reduced.

So, as line current drops, you know voltage drop will be also reduced. So, as the power factor will be improved and so on. So, all these things will hold even if we consider this R greater than X L. So, someone may question that the previous phasor diagram is drawn by considering this R is lower than X L, but what will happen if R greater than X L. In fact, all these things will be intact.

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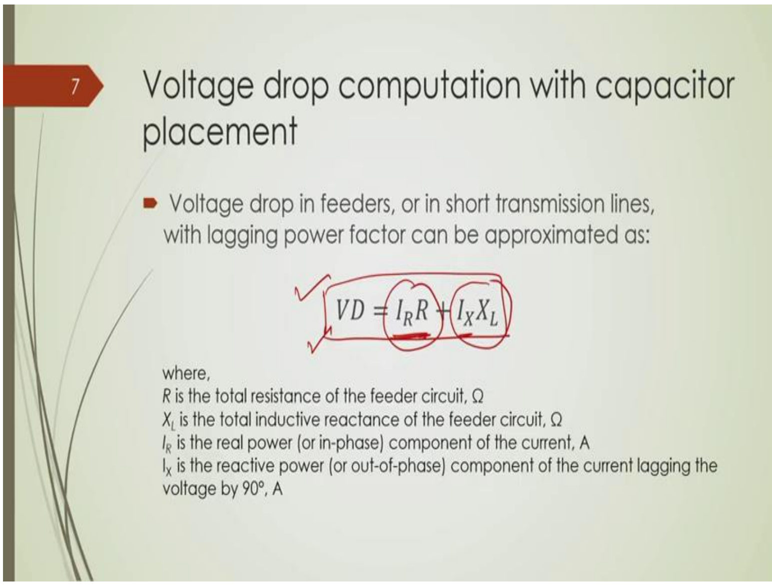

Now, from this voltage drop expression we will be having this two components of voltage drop one is in fact, this voltage drop will have two components one is called this you know. So, this voltage drop is basically if you extend this then this is the component. So, this part is basically in phase component of this I S R drop. So, this will be equal to.

So, since this is angle theta. So, this will be equal to I S R cos theta ok and that will be the in phase component ok that will be the in phase component. And this part is basically since this is theta this will be also theta. So, this part will be equal to I S, I am talking about this magnitude only I S X L sin theta ok.

So, and you know that made difference of V S and V R is because of these two component only, one is I S R cos theta, another is I S X L sin theta ok. So, this voltage drop I can represent it by I S R cos theta plus I S X L sin theta ok and sometimes it is also rewritten as I S cos theta multiplied by R plus I S sin theta multiplied by X L. So, this is in phase component of the current and this is quadrature component of the current.

So, voltage drop is basically equal to in phase component of the current multiplied by R plus quadrature component of the component multiplied by X L. So, same is represented here. So, here you know I R I S cos theta is represented by I R R and I S sin theta is represented by I X that is I X X L. So, that is the way that we can also represent the expression for voltage drop.

So, here I R is not this actual current rather it is the in phase component of the load current and I X is not the actual current it is the out of phase or quadrature component of the load current ok. So, this is the expression for voltage drop, now you can see one thing that there is a provision to improve this voltage drop if we can improve both the components ok if we improve the both the components ok. So, those things I will discuss later on.

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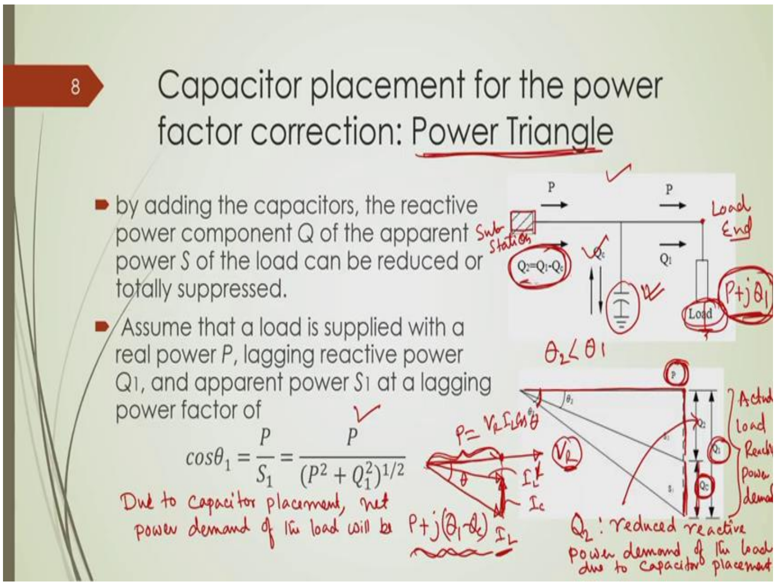

Now, before I move forward let us see another concept that is called power triangle ok. So, here we have a similar example i.e., here we have a substation. So, this is our substation or the source, and this is where this load is connected load end ok. And then near to this load we have a capacitor placed ok.

Now, once you have this you can see that we have a revision of this current drawn from this substation or from this source ok. We have seen this current drawn from the source is changed from I L to this I S dash or I S to I S dash ok. If so, then we can also draw this phasor diagram here suppose this is my receiving end voltage or load end voltage and this is the current actual load current.

Now, due to this capacitor placement we have seen that this load current is changed to here ok. So, you can see this is I L and this is basically I L dash and this is basically I C which change this I L or load current or current drawn by this load from I L to I L dash. Now if you multiply this V R component of this I L and I C and this I L dash then what we will get this projection of I L at this in phase component of this I L; if you multiplied with this then whatever you will get that will be active power that is P is equal to V R I L cos theta ok. Suppose this is theta ok.

Now, this in phase component will remain same even after this your capacitor compensation or in even after the placement of the capacitor ok. So, here in the power triangle this is basically represented the in phase component of the this power which is basically multiplication of V R with in phase component of the current that is I L cos theta and this quadrature component is of course, this reactive power. So, Q 1 was basically reactive power demand of this particular load; P is basically active power demand of this flow.

So, basically this load is consuming P plus j Q 1 ok. Now if you provide a capacitor we inject a current I C; that means, it provides some reactive power by injecting a Q C here; then the net reactive power demand of this load that will be due to capacitor placement net power demand of the load will be P plus j Q 1 minus Q C. It does not mean that actual load is changed, the load is basically remain same i.e., load is having this power demand active power demand P, and reactive power demand Q 1.

But since this Q C amount of reactive power is locally supplied by this capacitor its actual load demand is changed to that ok, and that is why you can represent this in this by using this concept called power angle. So, here this is your P, this is your actual load demand, actual load reactive power demand ok; and this is the reduced reactive power demand of the load. So, this much or rather Q 2 is basically reduced reactive power demand of the load due to capacitor placement; due to capacitor placement ok.

So, actually this load demand remains same, but capacitor is locally supplying some amount of reactive power demand of the load and thereby actual reactive power demand of the load is getting reduced. So, that is what I am trying to explain and that is why you know and this results in the change of the power factor angle from theta 1 to theta 2, here also you can see theta 2 is lower than theta 1; that means, cos theta 2 will be higher than cos theta 1. So, net power factor of the load will be higher ok.

So, here you can see cos theta 1 you can find out because our real power will remain same there is no real power source here except that substation. So, whatever real power the load was drawing before this capacitor placement is the same real power or same active power this load will draw even after this capacitor placement ok.

But its net reactive power which is the load is drawing from the substation is getting reduced. So, actual reactive power the substation previously was providing the entire Q 1 reactive per demand of the load. Now, since Q C amount of reactive power is locally supplied by this capacitor. So, actual reactive power drawn from the substation is reduced to Q 1 minus Q C that is Q 2. So, this is the effect of this capacitor placement ok.

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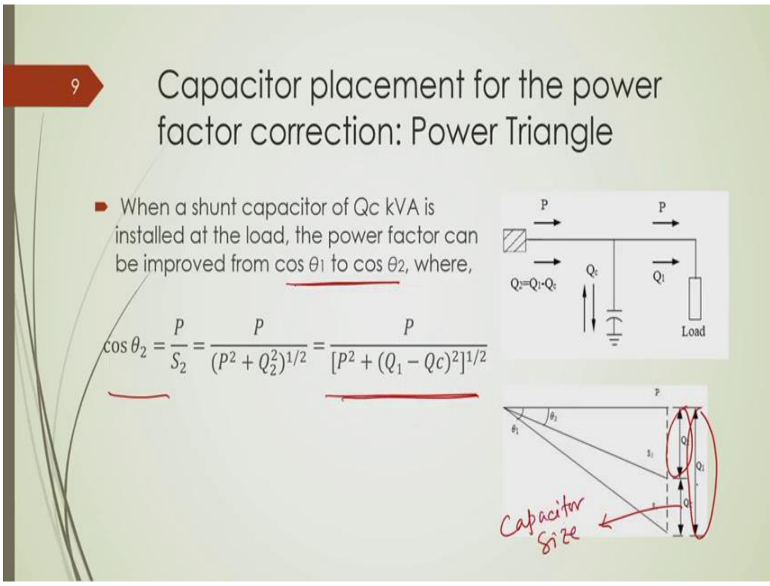

So, thereby this power factor angle is basically improved from this cos theta 1 to cos theta 2 and; obviously, this cos theta 2 you can determine from this power triangle ok.

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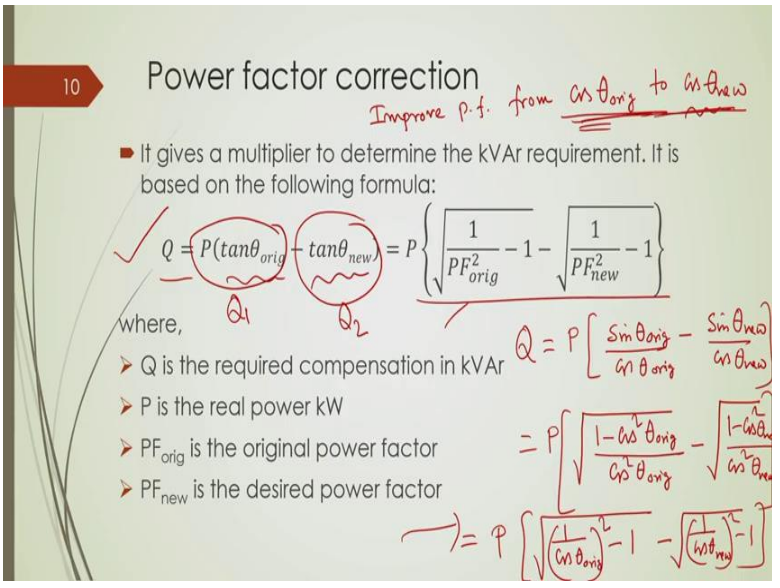

And sometime, you will see some of the numerical problems where power factor correction is required and any industrial load is intended to improve a power factor from some value to some value ok. From let us say 0.7 to 0.8 or 0.7 to 0.9 and you so you are a power systems engineer you will be asked to determine that how much should be the size of the capacitor or capacitor bank in order to improve this power factor from 0.7 to 0.9 ok.

For those kind of problems, you can directly solve that how much reactive power you require from the capacitor by using this expression that is Q is equal to P tan theta original means the actual value of theta is basically representing that load phase angle and this tan theta new is basically the new angle which is of reduced magnitude after improving the power factor.

So, basically we are intending to improve the power factor from cos theta original to cos theta new of course, cos theta new will be higher than cos theta original ok. Now, how to do that? you can simply express this because this P tan theta original is basically representing this is P and this is tan theta.

So, basically this is nothing but this Q 1 which is the actual power demand of the load. So, this part is basically Q 1 and this part that is P multiplied by tan theta new is basically this part that is Q 2. So, that is Q 2. So, if you take the difference of that whatever you will get that is the capacitor size capacitor size ok.

Now, you can replace this tan theta in terms of power factor in order to do so, it is very simple. let us write it this is P multiplied by this tan theta. I can write it as sin theta original divided by cos theta original and similarly this is also sin theta new and this is cos theta new ok. Now I have to replace this sin theta by cos theta how can I do.

So, I can write it like this is equal to sin theta is represented by 1 minus cos square theta divided by cos square theta, similarly here this is 1 minus cos theta new square divided by cos square theta new.

So, this is basically equal to this. So, this part you will see this part will be minus 1. So, this will be 1 upon this cos theta original square minus 1. So, this will be equal to 1 minus cos theta new square minus 1.

So, this is nothing but this ok. So, if you can remember this formula you can directly get the capacitor size in order to improve this power factor from cos theta original to cos theta new, otherwise you can do step by step analysis to find out what will be you know active power demand of the source what should be the reactive power demand after implementation of this capacitor after placement of the capacitor.

And step by step analysis will provide you the result. Then that does not need to have this particular formula to keep in memory ok.

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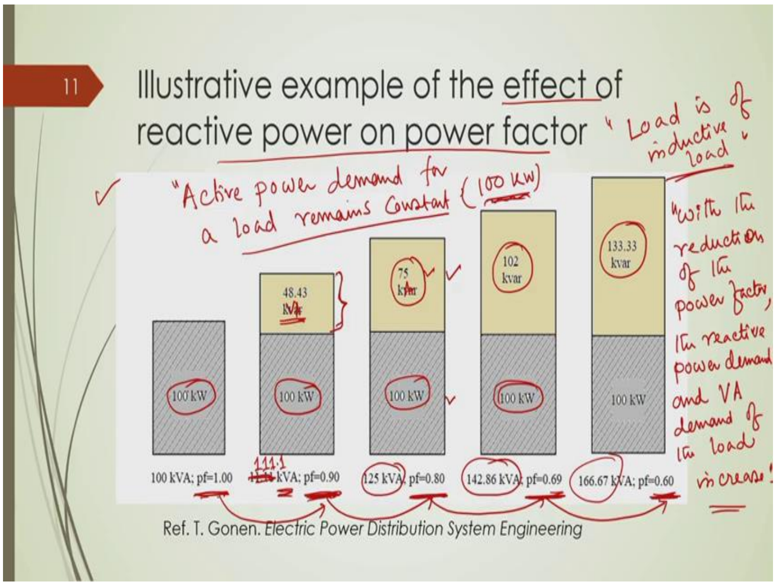

So, this is an illustrative example to show the effect of reactive power on power factor ok. So, in this example we assume that active power for a load remains constant ok. So, we assume that the active power demand of a load is constant and that is 100 kilowatt. Now we have 5 different scenarios one is when power factor is equal to 1, when is when power factor is equal to 0.9, when another is when power factor is equal to 0.8, power factor is equal to 0.69 and power factor is equal to 0.6.

So, when power factor is equal to 1 that is unity per factor for a particular load whose demand is 10 kilowatt its reactive power demand would be 0 its reactive per demand is with would be 0, because it is operating at unity power factor. Now when this power factor is 0.9 power factor is changed to 0.9 lagging. So, here we are all considering the power load is lagging ,the load is of inductive load. So, that is our assumption ok.

So, if power factor is 0.9 which is true for this load practically, all loads are of inductive. So, if this power factor becomes 0.9 that is it gets reduced from 1 to 0.9, then if we want to keep this active power remain constant to 100 kilowatt then you see this reactive power demand of the load increased from 0 to that much of KVAr ok. So, this also increases this total KVA demand of the load this is there is a mistake here typo this should be 111.1 KV ok.

So, you can see if power factor is changed from 1 to 0.9 both reactive power demand and KVA icreases. Now further power factor is changed from 0.9 to 0.8. So, for that condition reactive power demand is increased to 75 KVAr, active power remains same and since reactive power increase so, KVA demand is also increased KVA demand is also increases. So, there is an increase of reactive power as well as KVA demand.

Now, again if power factor is changed to 0.8 to 0.69 keeping this active power demand constant the reactive power demand to be; obviously, increased and this will increase the KVA demand as well kVA. Similarly, power factor becomes further reduced that is become 0.6 further you can see this reactive power is increased and KVA demand is also increased.

So, with the reduction of the power factor what we could see, the reactive power demand and volt ampere demand of the load increase. So, that is what the conclusion or that is what the illustrative conclusion that we can see. So; that means, if we have a load which is consuming same active power, but its power factor is getting poor and poor which will result in higher and higher amount of reactive power demand also which will result in higher and higher KVA ok.

So, an industry if it operates in lower power factor it means that it is drawing higher amount of reactive part from the source or from the substation and also subsequently its volt ampere demand also increases. So, one thing also you can alternatively think about that if this power factor is getting poor and poor what is the impact and utility can see keeping that active power demand of the load remains same. So, what impact the utility will see is that utility will see the reactive power demand of the load is getting increased.

And also this volt ampere increased and due to this higher and higher reactive power demand which is which there if there is no other source of reactive power in between the utility will be responsible to meet ok. So, utility will see that even though it is transferring same volt ampere of power, where this active power remains same because of higher and higher reactive power we need to support more amount of KVA.

So, subsequently your infrastructure the distribution line that we are basically constructed we have already basically constructed needs to support more higher amount of KVA demand ok. So, that is the impact.

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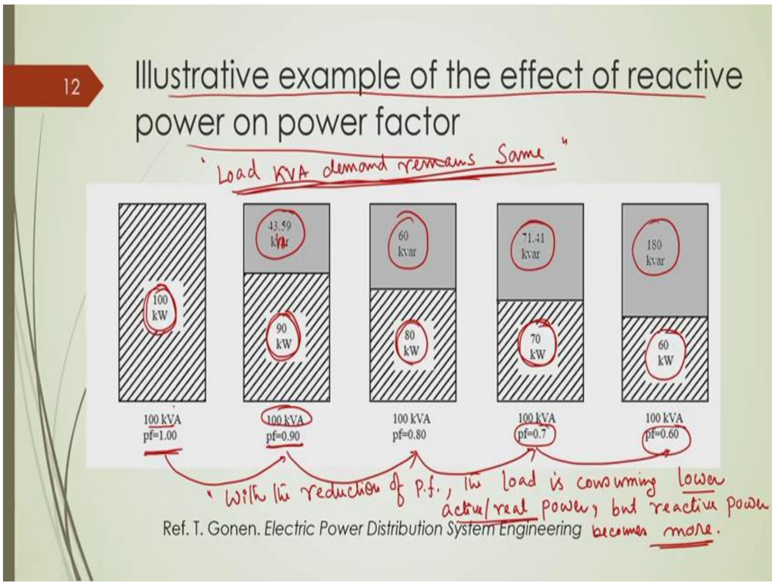

Similarly, there is another illustrative example; where load KVA demand remains same and the power factor is changed. So, what will be the impact, you can see here my load KVA demand I want to maintain same. So, if power factor is 1 that is of unity per factor then 100 KVA correspond to 100 kilowatt ok. Now what will happen if power factor is changed to 0.9, keeping this KVA demand constant that is 100 KVA that is 100 KVA.

So, at this scenario you will see that real power or active power is reduced from 100 to 90. And reactive power is increased from 0 to 43 ok 43 KVR now further this power factor is suppose reduced that is 0.8 it becomes 0.8. You will see that active power or real power is will be reduced to 80 kilowatt and reactive power will be increased to 60 KVR.

Then again this power factor is change to 0.7 again this will lead to this reduction of active power to 70 kilowatt and it will lead to increase in reactive power to 71 kilowatt. So, further reduction of power factor will again reduce this active power and it will increase this reactive power.

Now, as a utility what this electrical utility will see that the utility is basically generating or it provides energy to a load. So, that this load will consume a certain amount of active power and that is why it will be charged certain whatever amount of you know kilowatt hour of energy or whatever amount of units of energy it will consume.

Now, if this load power factor is getting poor; that means, actual this useful power that this load is consuming is become less. So, what we can write with the reduction of power factor the load is consuming lower active or real power, this is under this constant under this consideration that load KVA demand remains same. So, what will be the difficulty for the utility? So, utility see that actual or useful power becomes less, but reactive power becomes reactive power demand becomes more ok.

So, in both the cases the ultimate outcome is that the reactive power demand of the load will increase. So, in one case in order to keep this you know active power demand remain constant; the utility need to have a infrastructure with higher amount of KVA. So, that it can provide higher amount of KVA ok; and here if you keep that KVA if utility is not desires to support that amount higher amount of KVA, it wants to keep the KVA demand constant, then what utility will see it will see its active power or useful power the load is drawing is getting reduced ok so, which is of course, not the favorable situation for a utility. So, these are the two consequences ok.

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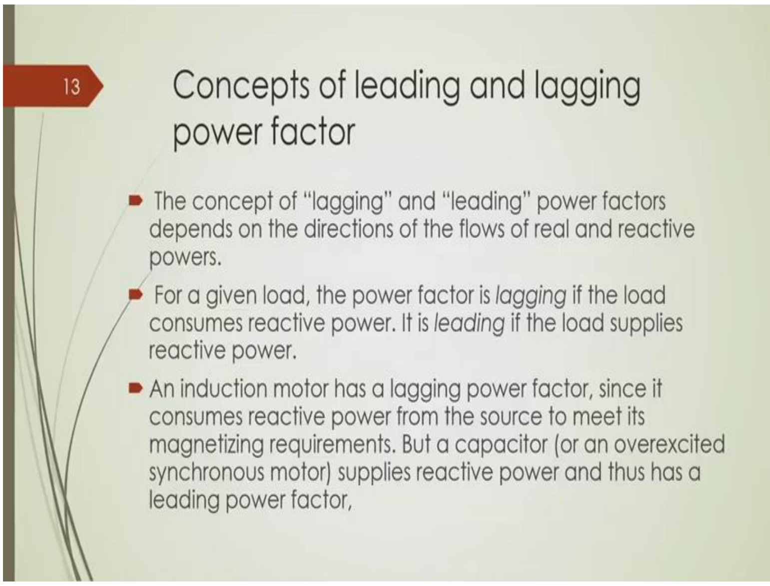

And that is why you know it as for a utility this power factor correction is an important aspect ok. So, with this I will stop today and I will continue with this from the next lecture.

Thank you.