Operation and Planning of Power Distribution Systems
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Lecture - 22
Reactive power compensation: Numerical examples

So, in my last lecture, I started discussion on Reactive power compensation of power distribution networks with capacitor placement, ok. And I explained how a capacitor placed in parallel to a load can improve this voltage profile; it can reduce the current flow through the line and it also improves the power factor of the load, ok.

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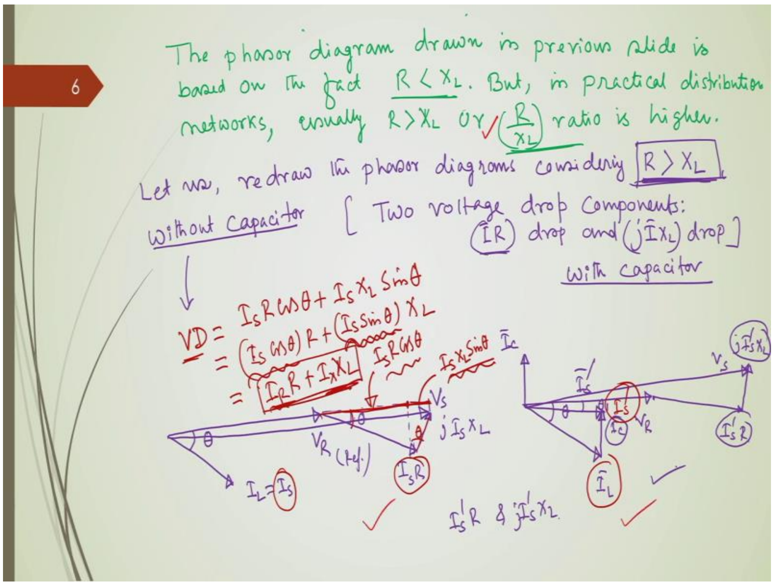

So, in fact if I go back and show you this phasor diagram, which I have drawn my last lecture or previous lecture.

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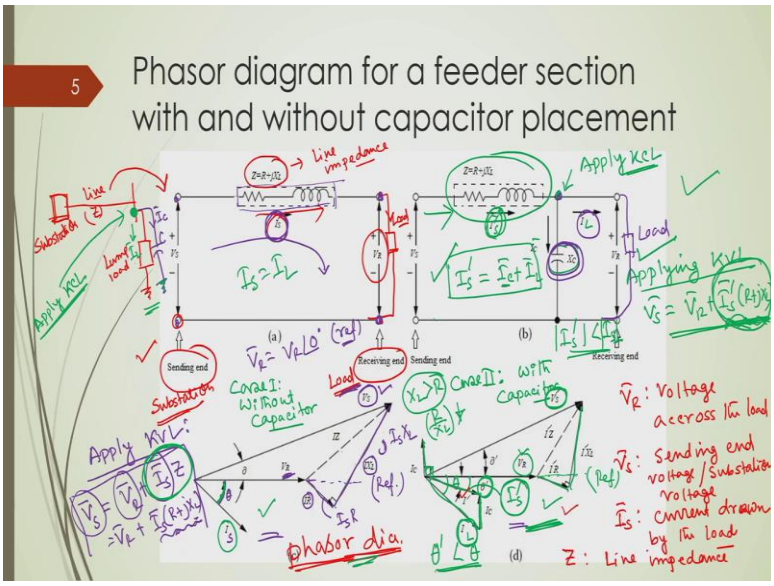

You can see that these three are discussed, one is that reduction of this line current, which is visible over here; another is improvement of this voltage profile, so that you can eventually compare this voltage drop or the difference of voltage of this receiving end voltage and the substation voltage for these two cases. Then you can understand this difference of voltage of the sending end side and this load end would be lower, if we have a capacitor placed in parallel to that plot, ok.

And this is explained for a different R by X ratio, ok. So, since distribution networks are having higher R by X ratio; so how would be the phasor diagram, those things are explained in these two figures.

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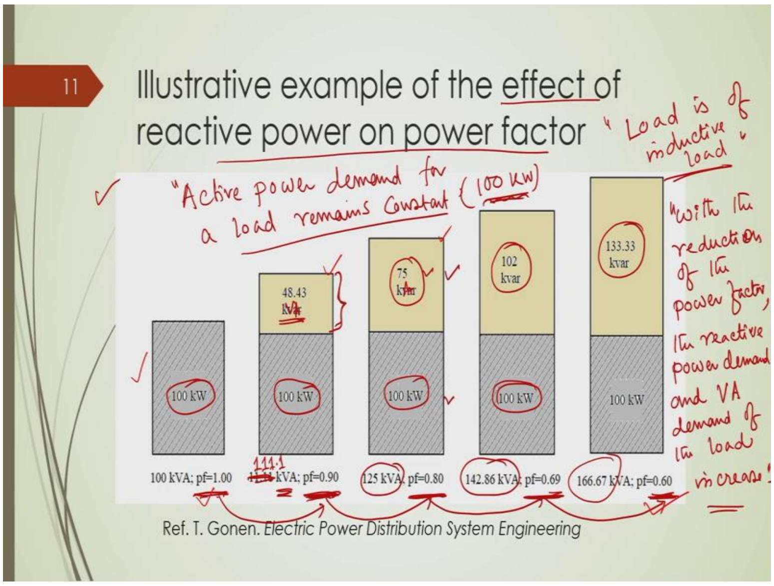

So, and finally, we have shown you, I have shown you an illustrative example for a typical case, in which, suppose, keeping this active power constant or keeping the active power generation constant for a particular generator, who is generating or you can eventually consider that for a substation, from where you are feeding power to the loads or customers.

Keeping the active power flow constant for through the substation, if we see that load power factor deteriorates ok; load power factor is getting poor starting from this unity power factor to a power factor 0.6, 0.5, then you will see this entitles to higher reactive power demand and this results in higher reactive power demand and thus, it becomes an additional burden to the distribution network operator to meet with, ok.

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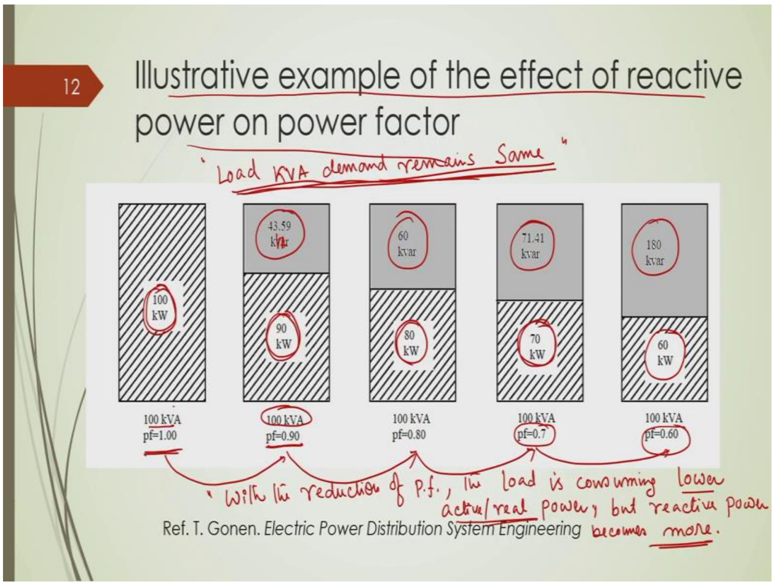

And there is a case also, if we keep this, keep the volt ampere flow from a substation constant and the load power factors are getting deteriorated, then you can see eventually the flow of active power will be get reduced, ok. So, these are nice examples to understand that effect of this power factor on the operation of a typical distribution network and the requirement of reactive power compensation locally, ok. So, these illustrative examples clearly show.

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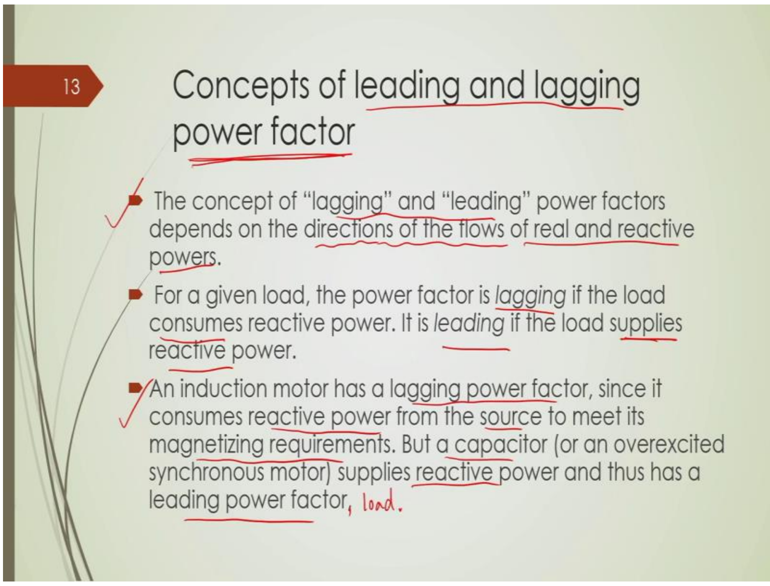

Now, here we will talk about the concept of leading and lagging power factor. Sometimes this confuses for the practicing engineers or students that, how do you define this leading and lagging power factor.

So, the concept of lagging or leading power factor normally we decide by a type of load, ok. For inductive type of load, we call that it is a lagging power factor load; for capacitive type of load, we call it as a leading power factor load, ok.

Now, alternatively we can define this lagging and leading power factors by something like this. We can define it with the directions of the flow of real and reactive power. So, real power will, of course, flow every time from the source end to the load end and for reactive power we have two concepts; one is called consumption of the reactive power, another is production or supply of this reactive power, ok.

Now, for those loads which consume reactive power along with this active power, we call them as lagging load, ok. And those loads which provide us the reactive power or who supplies the reactive power, we call them this leading load, ok. So, this is another way to define these lagging and leading loads; both definitions are with the same concept, but this is how we can define.

An induction motor has a lagging power factor, because it consumes reactive power from the source to meet its magnetizing requirement. But a capacitor supplies reactive power and thus it is a leading power factor load, leading power factor load, ok. So, this is something that one should understand, ok.

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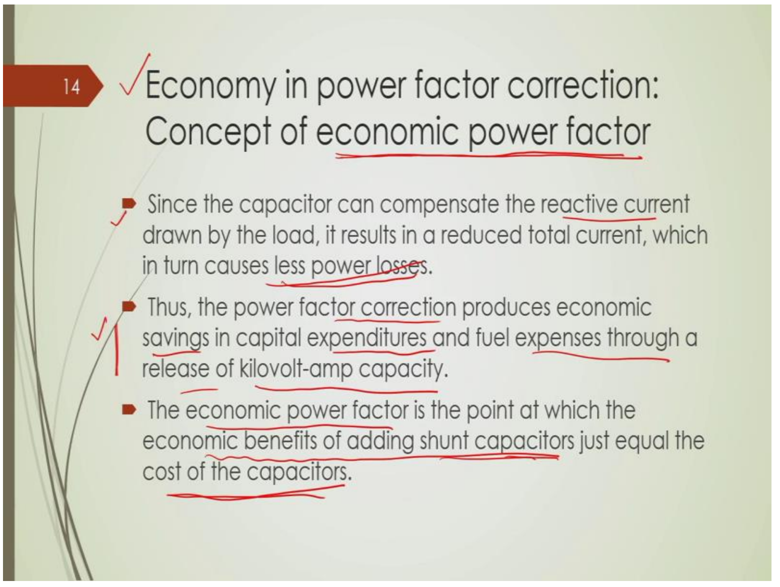

Now, there is economy involved in the power factor correction, or this power factor correction is similar to the reactive power compensation, ok. And there, you can define an economic power factor, you can define an economic power factor. So, how do you define an economic power factor, ok? So, as we have seen that a capacitor placement can compensate the reactive current drawn by the load.

So, capacitor typically draws a current which draws the reactive power ok, which supplies the reactive power and therefore, it reduces that power loss, which we have seen in. Why it will, it can reduce power loss? Because a capacitor placement in parallel to a load reduces the line current, ok.

And if line current reduces, so these line losses which are proportional to the square of the current will automatically get reduced, ok. So, power factor correction produces an economic savings in terms of capital expenditure and fuel expenses through a release of kilo volt ampere capacity. So, release of this kVA capacity, this is something that we will, I will come later on. But one thing one could understand that, with the placement of capacitor in any part of a distribution network will reduce the losses which took place in a distribution line, ok.

And thereby, it enhances the saving, because power loss is a certain parameter which we always try to minimize. And capacitor placement is one of the approaches by using which a distribution network operator can minimize the power loss or energy loss of a distribution network, ok.

Now, this economic power factor is the power factor at which these economic benefits of adding a shunt capacitor is just equal to the cost of the capacitor; because for capacitor placement it needs capital investment, ok. So, in order to establish this capacitor, in order to install capacitor bank at any point of a network, it needs certain amount of investment, ok. And that investment should be paid off with the economic benefit that we get from this installation of the capacitor bank.

And that benefit we will get through the reduction of power losses ok, which I will come after some few minutes, ok.

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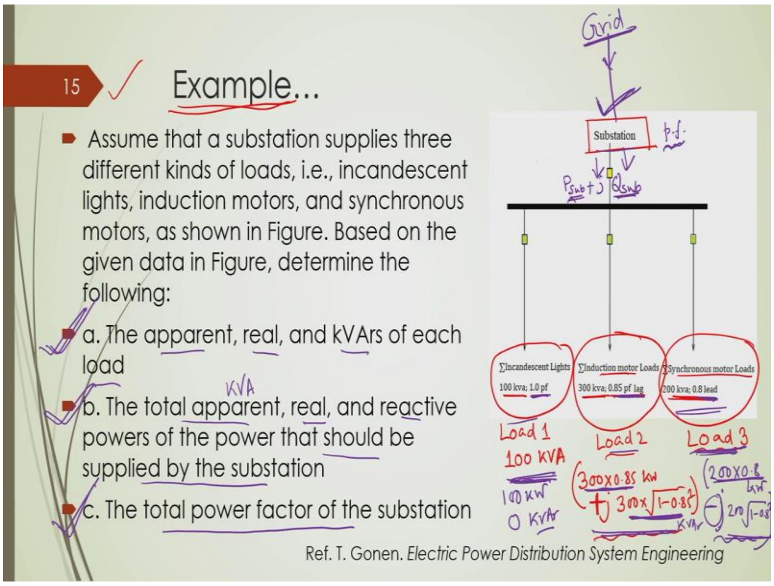

So, before that, I will show an example, numerical example to you. This example if you look at, we have a substation here and in a particular feeder, we have three different types of loads; this is load 1, this is load 2, and this is load 3, ok. And it is mentioned that how much this load 1 is; so load 1 is of a 100 kVA and it operates at unity power factor, power factor is equal to 1.

So, it consumes 100 kVA. Now, induction motor load; the load 2 is basically induction motor load, which consumes 300 kVA at a power factor of 0.85 lagging, ok. So, we can find out this load demand of this load 2, which consists of induction motors, ok.

So, we can find out this active and reactive power demand. So, active power demand will be 300 multiplied by 0.85 kilo watt ok, and reactive power demand will be equal to 300 multiplied by 1 minus 0.85 square; whatever that might be, that would be active and reactive part demand of this load 2, which is of induction motor load. Since it is a lagging type of load, it will consume both active and reactive power.

So, that is why we write it in terms of p plus j q ok, where p is your active power demand and q is your reactive demand, ok. Similarly, load 3 is a synchronous motor which operates at 200 kVA at 0.8 power factor leading, ok. So, synchronous motor you know it has two modes of operation; one is over excitation, another is under excitation. In one of the modes, it provides or it supplies reactive power to the system; in another mode, it consumes reactive power.

So, accordingly we can find out; since it is operating at leading power factor, so it will definitely supply reactive power to the system, ok. So, we can find out this load 3, load 3 active and reactive power demand, which will be 200 multiplied by 0.8 kilowatt plus minus j.

Because, why it is minus? Because it supplies reactive power to the system, minus j multiplied by j multiplied by 200 again 1 minus 0.8 square ok, so whatever that might be. So, that would give you the active and reactive power demand of this load 3, which is a synchronous motor load, ok.

Now, we have three different types of loads; one is unity power factor load, one is lagging load, another is leading load and all these loads are supplied by a single substation. So, based upon these data, you need to find out this kVA kilowatt and kVAr or; that means apparent real and reactive power of individual loads, ok.

Which already we determined, here our active power load is 100 kilowatt and reactive power load is 0 kVAr, ok. And for load 2 this is my active power demand and this is the reactive power demand, so this will be kVAr. Similarly for load 3, this is the active power demand and this is the reactive power, which is negative; because it supplies reactive power to the system, ok. Now, question number b is total apparent, apparent means total kVA, total kVA, real and reactive power that should be supplied by the substation.

So, what would be the total active and reactive power, suppose if we represent it by P sub, P sub plus j Q sub; then what is the value of P sub and Q sub? So, that needs to be determined, this is the question number b. And question number c is the power factor of the substation. So, what is the power factor of the substation? So, this power factor will be function of the individual loads, ok.

So, I will come to that, ok. So, the first one is very simple. So, you need to determine these individual loads, active and reactive power demand; the second question is the total active and reactive power demand of the substation that is P sub and Q sub, which are function of course, the individual load demand, ok.

And similarly, question number c is the total power factor of the substation, ok.

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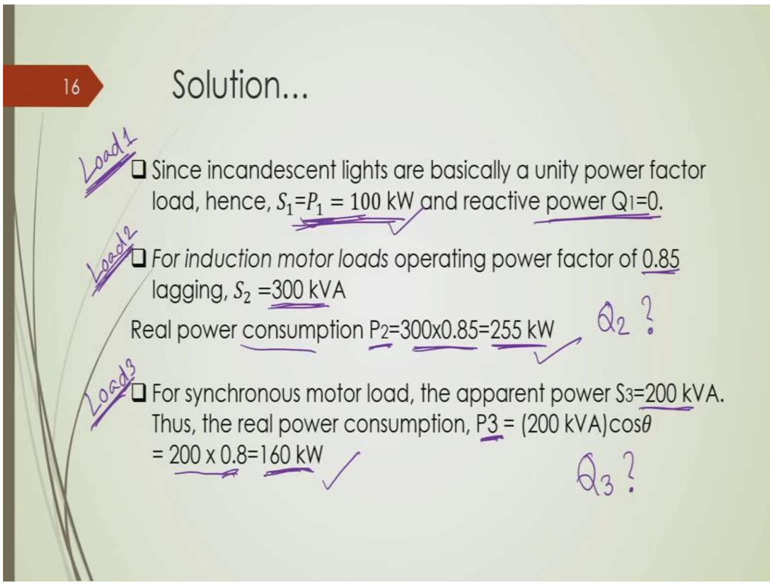

Now, as I have shown you, so this incandescent lamp light which is load 1, this is our load 1; which operates at unity power factor, so it consumes 100 kilowatt and reactive power consumption is 0, ok. Here P 1 is corresponding to the active power demand of load 1 and Q 1 corresponds to the reactive power demand of the load 1. Similarly, here, this is for load 2, which gives you the induction motor loads operating power factor 0.85 and its kVA demand is given as 300.

So, real power consumption as I have shown you, so it is 300 multiplied by a 0.85, which is coming out to be 255, 255 kilowatts ok. And this is for load 3, this is for load 3.

And so, here P 2 stands for the active power demand of this load 2, P 1 stands for the active power demand of the load 1 and obviously, P 3 would be active power demand of the load 3. Now, for load 3 this kVA demand is given as 200 kVA and power factor is given as 0.8. So, we can find out the active power demand of this load 3, which is equal to P 3; once that is 200 multiplied by 0.8, that is 160 kilowatts, similar to what we got in the last slide.

Now, we need to also find out what would be the reactive power demand of load 2, that is, what would be the value of Q 2 and what would be the reactive power demand of load 3, that is, what would be the value of Q 3, ok.

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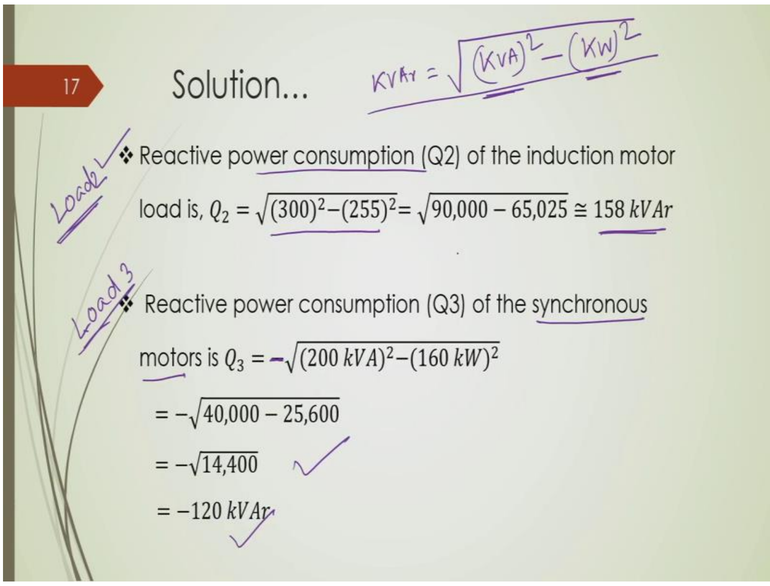

Now, here we determine that for load 2, this reactive power consumption is; either you can find out just by using this expression, which is nothing but kVAr is equal to kVA square minus kilo watt square. Since we already know that kVA and we already determine this kilowatt; so we can find out what would be the kVAr, that is reactive power demand of this load 2.

Similarly, we also can find out what would be the reactive power demand of load 3, which is of synchronous motor operating at leading power factor or which provides reactive power to us; that is why this is purposefully kept as negative, because already you have seen this is negative.

So, you know that 200 multiplied by root of 1 minus 0.8 square which is equal to 200 multiplied by 0.6, so that is equal to 120 kVAr, ok. So, alternatively you can use this formula to find out this kVAr demand of this load 3, ok. So, we have answered this question number a, ok. We determine this real and reactive power demands of all the different loads load 1, load 2, load 3, ok.

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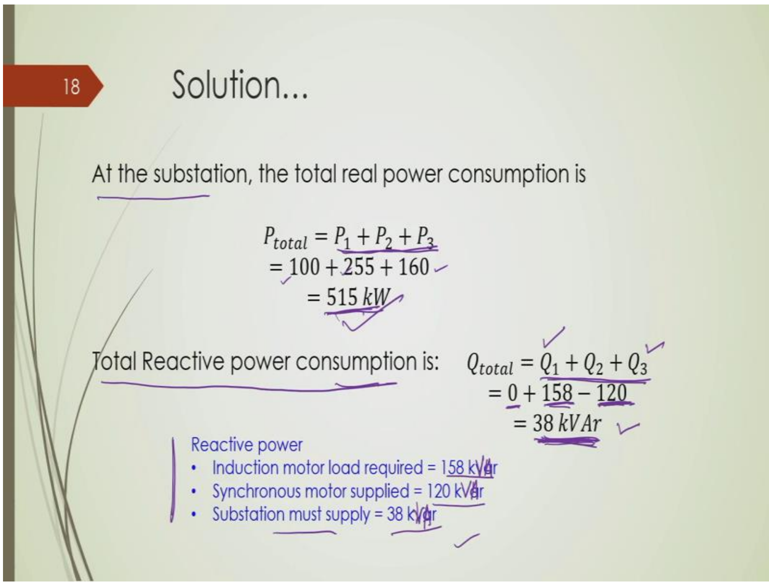

Now, next question is what would be the load demand of the substation. So, at the substation the load demand will be the total demand, which is algebraic sum of individual active power demand and individual reactive power demand.

So, if you sum up this individual active power demand, that is 100, 255 and 160 which we obtained here 100, 255 and 160 then it will come out to be 515 kilowatts, ok. Similarly, total reactive power consumption would be summation of Q 1 plus Q 2 plus Q 3; I had this Q 1, Q 2 and Q 3 are the reactive power demands of load 1, load 2 and load 3 respectively, ok. So, for load 1 this reactive power demand is 0; for load 2 it is plus 158, and for load 3 it is minus 120, ok.

So, which gives the value 38, ok. So, you can see, this is how it is determined that induction motor load required 150 kVAr ok and synchronous motor supplied 120 kVAr, so substation must supply 38 kVAr, ok. And so, this 38 kVAr is the net reactive power which is supplied by the substation or which is to be supplied by the substation, ok.

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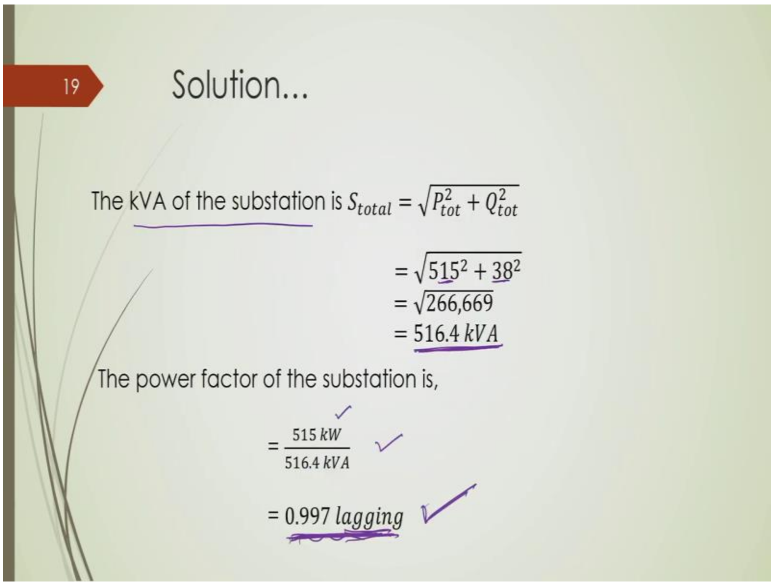

Now, with this, we can find out this total kVA demand which is supplied by the substation, which is coming out to be root of this active power demand and reactive power demand, which is coming out to be this, ok. And we know this active power that needs to be supplied by this substation is 515; we know the kVA demand which needs to be supplied by the substation is 516.4.

So, if you take the ratio of these two, you will get that how much would be the power factor of the substation as a whole, ok. If you consider the whole thing as load, then what would be the power factor of the aggregated load, which consists of these three loads that is load 1, load 2, load 3 that would be 0.997. Now, why we call it as a lagging load?

Because it is, it demands a positive reactive power from the substation ok; because the difference of 150 and minus 150 and 120 leads to a positive reactive power demand, that means effectively this substation needs to provide this reactive power to these three loads, which consist, constitutes a composite load, ok. And why it is of so high value that 0.997?

Because you can see as compared to the active power demand, this reactive power demand is very very less. Why this reactive power demand is very very less? See this active power demand where it is 515, the reactive power demand is only 38, ok.

Now, why it is so? Because this load 3 it provides certain amount of reactive power to the system, ok. So, therefore, it the objective of this problem is to understand that, here you can see we have three individual loads; one is of having unity power factor, another is 0.8 power factor leading, which means that whatever this reactive power demand we have on the load 2, partially it is made by this load 3 itself, ok.

So, whatever the reactive power demand we have for load 2, partially it is made by this load 3 itself and that is why this power factor is so high, power factor is so high close to the unity.

Otherwise, it would have been a much lower value, it would have been much lower value. You can imagine that if this Q 3 also demands this 120 kVAr of reactive power instead of supplying it; so what would have been this total reactive power demand? In that case total reactive power demand would have been 150 plus 120, 158 plus 120 which is equal to 278. And for that you can try the computation calculation, then you can see that reactive power would have been some much lesser value, close to 0.8 or something like that, ok.

But it is due to that this load 3, it is a different type of load; it is a synchronous motor which consumes active power, but it provides reactive power, then overall power factor of these three aggregated loads is improved to almost unity power factor, ok. So, this is the essence of having this problem. So, if we have, you know, local supply of this reactive power like, this what synchronous motor loads did; then that amount of reactive power we need not to bring from this substation.

Now, substation means, you know substation is connected to the sub transmission system or this power grid, so that much of reactive power we need not to bring from this grid, ok.

And grid, what is the source of the reactive power of a power grid or a power network as a whole? It is the synchronous generator or the generator, which are located in the different parts of the typical power transmission network, they are the supplier of this reactive power. So, with this load 3, we need to; we can avoid this, bringing this equivalent amount of reactive power from all the way of the generating station to this particular substation. So, that is what one of the advantages, ok. So, that is one of the advantages, ok.

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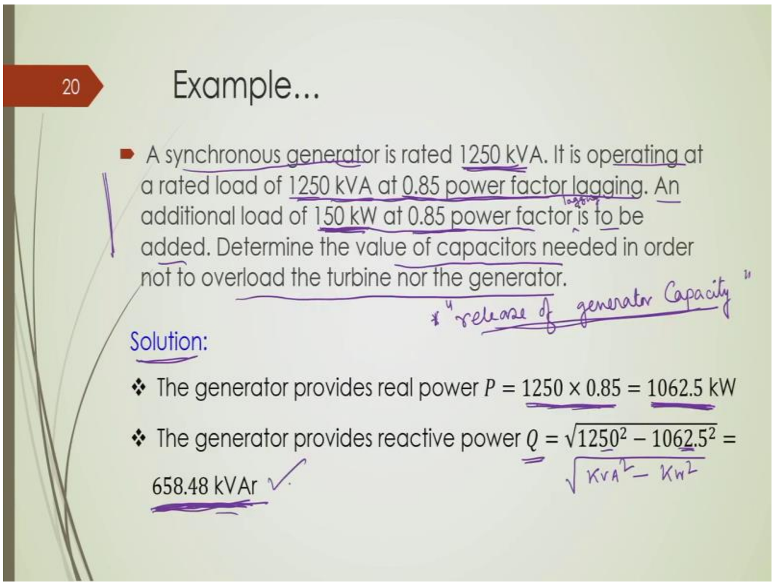

Now, we have another example, this example is of a synchronous generator; this example is of a synchronous generator, which is rated 1250 kVA, which is rated 1250 kVA, ok. And it is operating at a rated load of 1250 kVA at 0.8 power factor lagging ok, at 0.8 power factor lagging. An additional load of 150 kilowatt at 0.8 power factor, this is also lagging; this should have been mentioned, this is also lagging; is to be added to the generator ok, to the generator load.

Now, in order to do so, what should be the value of the capacitor to be placed, so that this overall generator and turbine set would not get overloaded, would not get overload? So, this is the problem, say generator, which is rated 1250 kVA, it is supplying 1250 kVA amount of load at 0.8 power factor lagging, ok.

Now, if there is another 150 kilowatt of load, which is also of same power factor that is 0.8 power factor lagging is to be added to the load of the generator; then of course, this generator cannot supply this additional load, because it is already working at this rated load, ok. So, we need to have certain arrangement, so that we can release some of the capacity of the generator and that capacity would be utilized to supply this additional load. So, this is called release of generator capacity.

So, this is called release of generator capacity. Now, if you look at the solution, you can understand what do you mean by release of generator capacity, ok. So, let us see how it can be solved. Now, first we will find out of course, this generator is supplying 1250 kVA of load at 0.8 power factor lagging; so that means, that corresponds to how much active power it is supplying and how much reactive power it will supply, ok.

So, active power it is supplying is, of course, this 1250 multiplied by this power factor that is 0.85, which is 1062.5 kilowatt. So, that is 1062.5 kilowatt, ok. Now, this is the active power the generator is supplying, ok. And along with generator is also supplying this reactive power demand of the load; because load demands, you know, 1250 kVA at 0.8 power factor lagging, it means that the load demands both active and reactive power. So, this is the active power demand of the load which is supplied by the generator.

Then how much, how much would be the reactive power demand; which is supplied by the generator which is very simple that Q is equal to, this is again the same formula we are using that is kVA root of kVA square minus kilo watt square. So, this is kVA square and this is kilo watt square, so which gives you that much of kVAr.

So, that means a generator connected to a load of 1250 kVA 0.8 power factor lagging means; the generator is supplying 1062.5 kilowatt of active power, which is the active power demand of the load. And it is also supplying a 658.48 kVAr of reactive power, which is the reactive power demand of the load, ok. Now, we have to see that how much would be the additional active and reactive power demand of the additional load. So, we need to supply additional 150 kilowatt of load at a power factor of 0.85 lagging.

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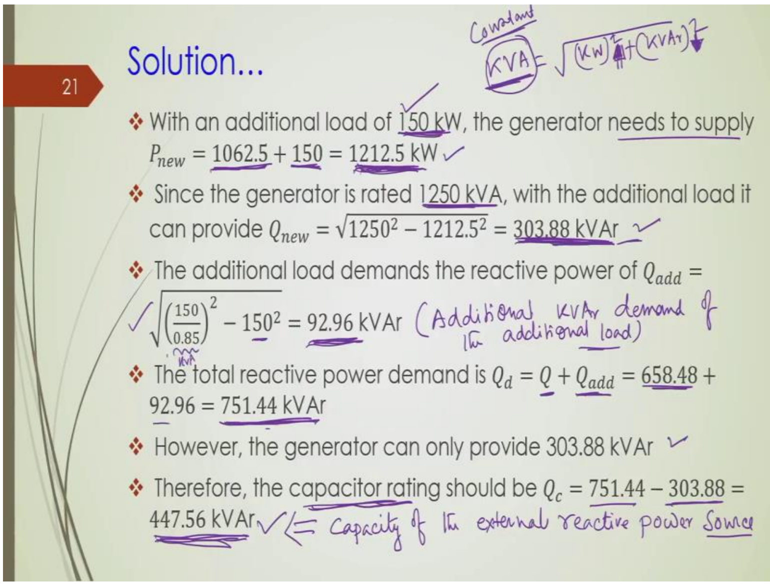

So, in order to do so, in order to supply additional 150 kilowatt of the load; the new generator, the generator needs to supply overall this active power, that is summation of this existing active power demand of the load and the active power demand of the new load.

So, this 1062.5 this is the active power demand of the existing load and 150 is the active power demand of the new load. So, if you sum up these two, so this is the amount of active power demand, which the generator needs to supply if it is used to supply this additional load, ok.

Now, you see that if the generator needs to supply that amount of kilowatt with the existing kVAr; it cannot supply, because the overall kVA demand would be higher than this rated capacity, ok. So, what we can do? We can determine that with this increased amount of this active power demand and by keeping the generator capacity to 1250 kVA, how much active power demand now the generator can supply. Because, as you know that kVA is equal to roots of kilowatt square plus kVAr square. Now, if your kilowatt demand increased, then in order to keep this kVA demand fixed or kVA capacity fixed; we have to reduce this kVAr demand ok, which is obvious, because if your kilowatt demand increased, then in order to keep the kVA demand fixed or constant, which is the rated capacity of the generator that much of kVA the generator can supply.

So, this kVA remains constant. So, this is a constant for this generator, constant parameter for the generator. Since kilowatt demand increase, so kVAr demand has to be less.

Now, what would be the kVAr demand under this condition that, we keep that generator capacity constant; that is, we keep the loading as per the generator capacity that is 1250 kVA and we will supply this additional 150 load, which increases the load demand to 112.5.

So, this means at this situation, the generator can only supply 303.88 kVAr ok; the generator can only supply that much of kVAr, which is less than the previous reactive power demand which the generator was supplying when there was no additional load, ok. Now, you can, you have to also find, because this additional load it is a lagging type of load, so it demands both active and reactive power.

So, its active power demand is that much; so how, what would be its reactive power demand? So, in order to find so, so find out this kVA demand of this load, which is 150 divided by 0.85. So, this gives this kVA demand of the load, kVA demand of this new load and this square minus this 150 square that is kilowatt square will give you that, that much of additional kVAr demand of the additional load. So, that is the kVAr demand of this additional load.

So, this also needs to be supplied, this also needs to be supplied ok; that means overall this reactive power demand with this existing load and this additional load will be 658.48, this is the reactive power demand of the existing load and Q add is the reactive power demand of this new load, that is 92.96. So, if you add, so this is the active, reactive power demand with the existing load and the new load; this is the total reactive power demand of the existing load and the new load.

Now, the generator can only supply this much of kVAr; more than that it cannot supply, because its capacity is limited to 1250 kVA, ok.

So, that means the demand is this, but this that much the generator can supply. So, the difference of these two, that is 751.44 minus 303.88, which is coming out to be 447.56 that much of kVAr needs to be supplied by an external reactive power source, so that the generator can be, can supply this additional load, ok. So, if you have a provision of external you know reactive power source, which will supply this amount of kVAr; then actually the generator needs to supply that much of kVAr, that much of kVAr and then the generator can easily supply this additional load, ok.

So, that is, that would be, that should be the capacity of the external reactive power source, reactive power source. And here we consider that the capacitor is the external reactive power source; so the capacitor rating should be that much amount. So, that the capacitor will supply that much amount of kVAr or that much amount of reactive power. So, that the generator reactive power supply requirement will come down to 303.88 and this will enable the generator to supply this additional 150 kilowatt of load.

So, this is something that one should understand that, with this external reactive power source or with the external capacitor; the generator is enabled to provide you the additional active power, ok. Because otherwise that, otherwise the whole reactive power requirement needs to be made by the generator itself; because loads are always having reactive power demand, ok. Without any external reactive power sources, it is only the generator who is providing this reactive power or who is meeting that reactive power demand of the loads, ok.

Now, if we have some external reactive power source somewhere connected near to the load, which supplies some amount of reactive power demand of the load; then eventually the reactive power which we need to bring all the way from the generating station to the load will come down, ok. And that is an additional advantage that will enable the generator to provide some additional active power, ok.

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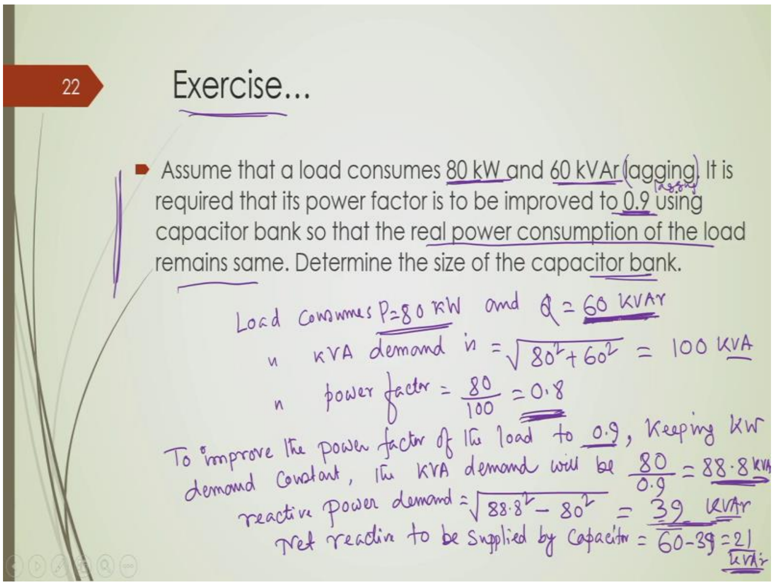

Now, there is an exercise for you and you need to solve this. This is very simple exercise if you go through there; if there is assumption that there is a load, which consumes 80 kilowatt of active power and 60 kVAr of reactive power which is lagging, lagging means it is consuming reactive power. Now, it is required that this power factor is to be improved to 0.9 lagging, 0.9 lagging using this capacitor bank, so that real power consumption of the load remains same ok.

So, determine the size of the capacitor bank, ok. So, we have a load which consumes 80 kilowatt of active power and 60 kVAr reactive power, it is a lagging power factor load. So, what would be the power factor of that load? So, load consumes that is P is equal to 80 kilowatt and Q is equal to 60 kVAr. So, what is the kVA demand? So, load kVA demand is equal to root over 80 square plus 60 square, which will come out to be 100 kVA, kVA, ok. So, now, load power factor, load power factor you can calculate; that is equal to 80 divided by 100, that is 0.8, ok.

Now, you have to improve this power factor point 0.8 to 0.9; 0.8 to 0.9, so that this real power consumption of the load remains same. So, that the real power consumption of the load is same, that is 80 kilowatt; then what would be the capacitor bank size ok? So, that we with the placement of the capacitor bank, you can increase the power factor from 0.8 lagging to 0.9 lagging, ok.

Now, what we can do, you can see that since real power consumption remains same; then in order to improve this power factor what would be the kVA demand of the load. So, to improve the power factor of the load to 0.9, keeping that, keeping kilowatt demand constant, the kVA demand will be 80 divided by 0.9, so which is equal to something like 88.8 or something kVA, ok.

Now, this will be our new kVA demand; keeping this kilowatt constant, we need to improve the power factor. Now, to do so, then what would be the kVAr demand? So, reactive power demand would be, reactive power demand would be 88 sorry 88.8 square minus 8 square 80 square; so whatever will come that much of reactive power, previously that reactive power demand would have was that.

And this reactive power demand I do not know what would be the value; whatever will come that will be much lesser lower than this 60 kVAr. Now, if it comes out to be, let us say, it is coming out to be let us say 39 or something, then this net, so that will be the kVAr demand if we want to improve this power factor from 0.8 to 0.9.

So, previously reactive power demand was that much, now it is that much, which is obviously lower. So, if power factor improves means, its reactive power demand is obviously lower.

So, we have seen in my previous illustrative example. So, the net reactive power to be supplied by capacitor equal to 60 minus 39, which is equal to 21 kVAr, so that would be the, in fact, size of the capacitor or capacitor bank. So, if the capacitor bank can supply this some fractional value of this reactive power demand of the load, obviously the load power factor will increase, ok.

So, that is the thing. So, this is a very simple problem.

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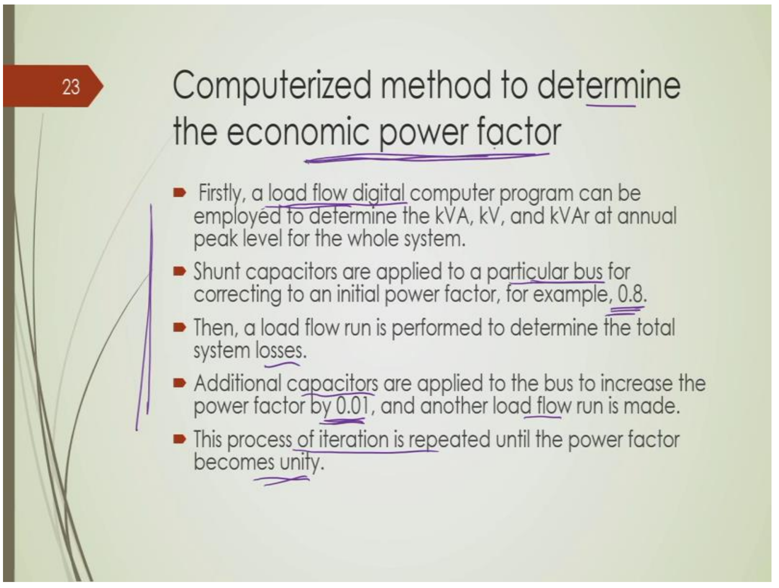

Now, we will come to some method to determine the economic power factor, to determine the economic power factor. As I said this economic power factor means, the power factor at which the gain, whatever this economic gain you will get through this placement of the capacitor will nullify the investment cost to install a capacitor in the network that is something called economic power factor, ok. So, as I said that in order to improve the power factor, we need to place a capacitor bank or capacitor; why we call it capacitor bank, I will come to that. Now, we need to place a capacitor.

Now, in order to place or in order to install capacitor, we need some investment; because we need to purchase this capacitor bank, we need to have some proper installation that will lead to a certain amount of investment. And after locating or after placing this capacitor, whatever gain we will get; gain in terms of this loss reduction or power loss reduction or gain in terms of other financial benefit, that gain should be equalized with this investment of the capacitor, then only this capacitor investment would be fruitful, ok.

So, how can we do this thing? This is a well-known paradigm of research in power system that, determination of this actual capacitor size as well as the location that where it should be placed, so that you will get financial benefit out of it, ok.

So, in order to do so, we can use our load flow program; that already I discussed this forward backwards with load flow program, you can write the programs code. And this program can be used as the sub routine to solve this problem that, how much should be this capacitor size and where would be the location of the capacitor, so that we can maximize the benefit of this capacitor placement. This is the well-known area of this power system research, ok. So, one of the ways of this doing so is explained over here in step by step.

So, first you place a capacitor and a particular bus or a node ok, which is having some power factor operating, power factor some value 0.8 lagging or 0.9, 0.7 lagging or whatever. Then you perform this load flow to determine that system losses and you keep this additional capacitor size, incremental additional capacitor size, so that you increase this power factor of the load to some value 0.01 or; that means you improve this power factor at least 1 percent, ok. And by performing this load flow, you find out that what is the financial benefit you are getting out of it.

And this will be an iterative process, so that this power factor becomes unity or power factor becomes an economic power factor.

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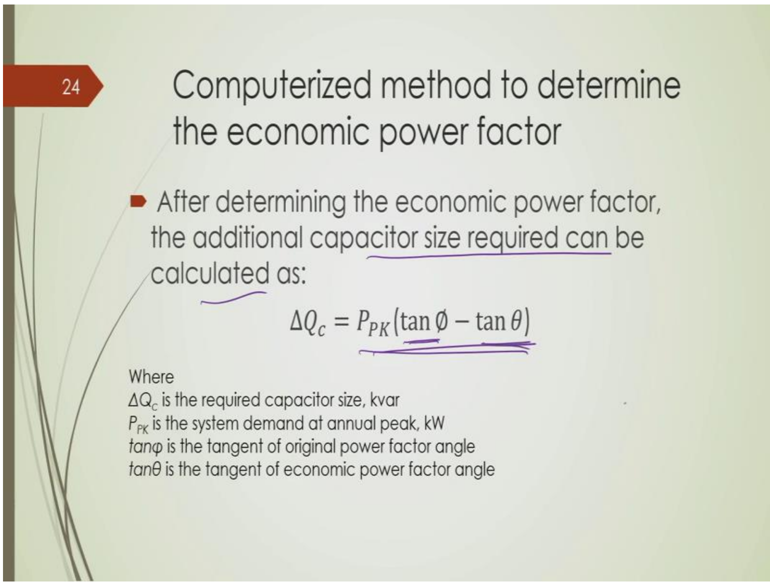

And then you can determine that what should be the size of the capacitor for by simply from this expression that, what is your target power factor angle and what is target tan of this power factor angle and what is your existing power factor. So, this is how one can proceed.

But as I said, this problem is not so simple like that, that one can solve like this and this is an area of the research on power distribution system. And if you simply search this with this keyword that reactive power compensation or capacitor placement in distribution networks, you will get hundreds of paper available in different search engines, ok.

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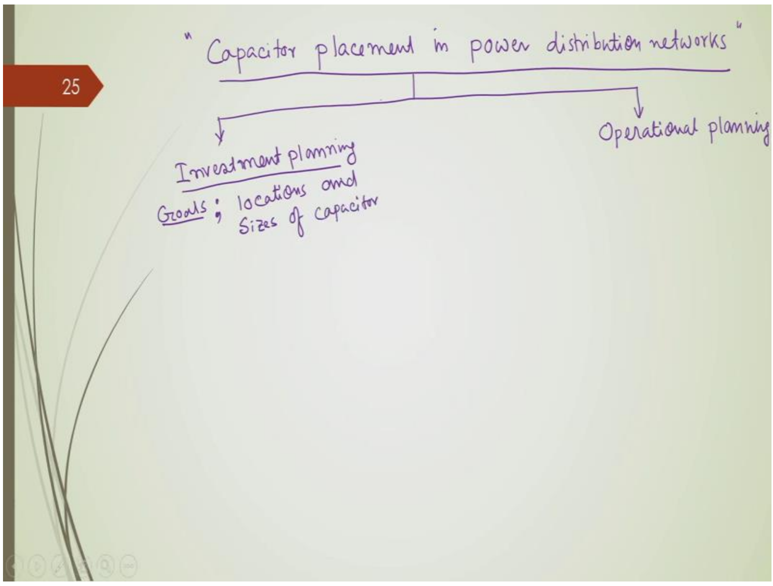

So, simply search with capacitor placement in power distribution networks, networks; if you search with this keyword, you will get hundreds of papers available in any of the search engines, ok. And this is the traditional research paradigm in which people are working since the last 20, 30 years, ok. So, this needs two types of and there are many approaches available, there are two possible approaches or two categorizations of these approaches; one is called investment planning, another is called operational planning, ok.

So, in investment planning, basically the goals are; the goals are to determine the location of the capacitor locations and sizes, location and sizes, I can write and here locations and sizes of capacitor, ok. Or I can write determination of, determination of location and sizes of the capacitor.

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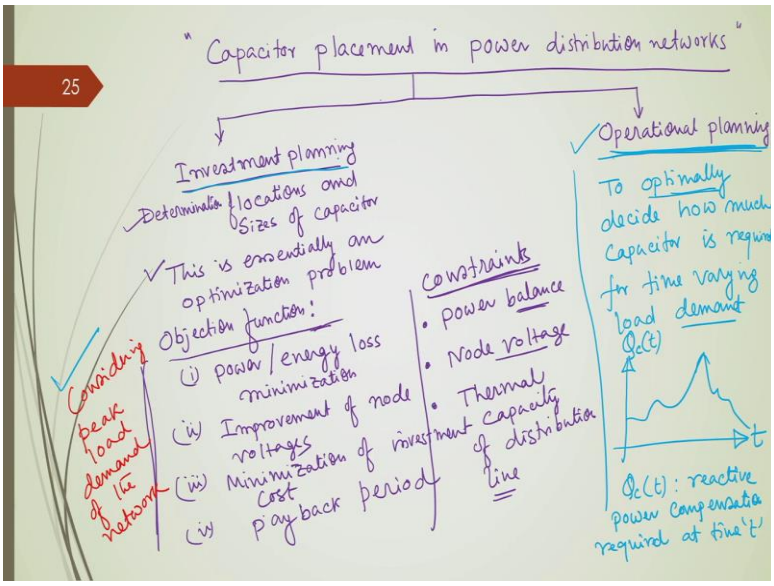

So, this is basically the goal of this particular planning problem. And there are many approaches available, in different approaches, different types of objective functions; this is essentially an optimization problem. So, this is essentially an optimization problem, ok.

So, this is essentially an optimization problem, where different types of objective functions are formulated. So, because you know in optimization problem; we formulate an objective function or a target function, which we need to maximize or minimize under some technical constraints, ok.

So, we have some objective functions which are formulated and these objective functions are typically are power or energy loss minimization, power or energy loss minimization; then improvement of node voltages, also this minimization of this investment cost, minimization of investment cost or minimization of the payback period.

What is payback period? Payback period means with this capacitor placement whatever financial gain we are getting, that gain will slowly pay back to the investment that we will do for installing a capacitor, ok.

Because capacitor bank installation it is a one step investment; you need to pay some money to installed capacitor bank in some part of your network and this investment will be paid back by the financial benefit we will be getting through this capacitor placement.

So, this is minimization of payback period right, simply I should write this payback period, payback period. And while doing this sort of optimization, while doing this optimization problem; one needs to understand that this is basically done considering, because it is a capital investment planning, so this is done considering this peak load demand of the network.

This is usually done by considering this peak load demand of the network, ok. So, all this investment planning etcetera are usually done by considering this peak load demand of the network. And these typical objective functions are optimized under the constraints; So, there are some technical constraints, there are some technical constraints; number 1 is of course power balance constraint that is equality constant, this is this can be made by this load flow approach and we perform load flow approach in order to meet this power balance constant.

But apart from that, we have node voltage constraint; that means this voltage at any particular node should lie in between a given lower and higher limits, ok and also thermal constraint, thermal capacity constraint.

So, thermal capacity constraint of distribution line means, of distribution line means, this line thermal line flow or line power flow should not exceed the thermal capacity or the ampacity limit of the distribution line. So, these are some constraints that one need to understand.

So, this is basically investment planning for capacitor placement in power distribution networks. But apart from that, we have some operational planning; we have some operational planning as we have indicated this. Operational planning is basically to optimally decide how much capacitor is required for time varying load demand.

As I mentioned over here for capital investment planning, we perform considering the peak load demand, ok. But this peak load demand will not sustain throughout the day, in fact it will sustain for a few hours or few minutes and throughout the day load will vary according to the load curve. And so, when load will vary, this active and reactive power demand of the all loads will also vary.

Now, according to this load curve, you can understand that this capacitive compensation or reactive power compensation that we require will also vary. So, with this varying load demand, with this time varying load demand; this capacitive compensation requirement will also vary and that variation should be determined by using this operational planning, so that we will get a curve, similar to the load curve, which determines that how much reactive power compensation we require in a particular instant of a day.

So, this object, the goal of this planning is to come up with how much reactive power compensation; suppose this is Q c t, I can write, where Q c t is basically the reactive power compensation required or reactive power compensation required at time t and this is our time. Now, how would be this plot that, throughout the day how would be the reactive power, what would be the optimal reactive power compensation we require?

So, these characteristics can be something like that or whatever; this is a typical value that during this peak demand, compensation requirement will also vary; similarly, when load demand is low, the compensation requirement will also be low. So, if you do not do so, if you consider as the same compensation value throughout the day; then during this low load condition, during this light load condition, this capacitor placement will cause some voltage rise issue, ok.

So, in order to avoid that, we need to go for this type of operational planning. So, how this operational planning will take place and how to determine this capacitor sizes and capacitor locations analytically, those things I will discuss in my next lecture, ok alright. So, this is up to this, I will continue this in the next lecture.

Thank you very much for joining.