Power Quality
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Analysis and Design of Three-Phase Four-Wire Passive Shunt Compensators
Lecture - 05
Passive Shunt and Series Compensations (contd.)

Welcome to the course on Power Quality. I mean today, we like to cover the topic of Analysis and Design of Three-Phase Four-Wire Shunt Compensator. In the last lecture, we covered Three-Phase Three-Wire Passive Shunt Compensator. [FL] today, we like to have four-wire compensator.

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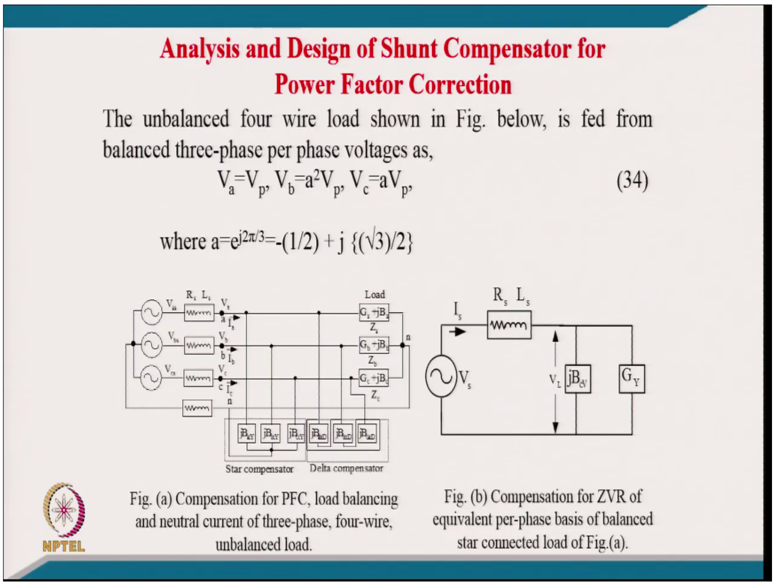

Well, we will like to first have analysis design of this shunt compensator for four-wire system for power factor correction. [FL] the unbalanced four-wire load shown here in a figure a, is fed from the balanced three-phase per, where the per phase voltage is V a equal to V p, V b equal to a square V P and V c equal to a V p; where, V P is the RMS voltage per phase and a is the operator for the 120 degree phase shift, e to power j 2 pi by 3 which is can be in rectangle can be written as a minus half plus j root 3 by 2.

Well, this is the network; I mean like you can see the three-phase four-wire system with unbalanced load on a phase, b phase and c phase, which is here Z a, Z b, Z c and connected to the neutral of this load because it is a four-wire system to the neutral of supply system.

Well, to compensate this load unbalanced load, I mean unbalance non-unity power factor loads of three-phase four-wire, well we have to have a two set of compensator; one set is connected in a star which you see it with a star connection or is known as your notation with the star connection with the notation of B Y.

And the another set of compensator which is here, delta connected across the three terminals of the point of common coupling which written as a with the notation of B D with the different notation. [FL] this network, I mean like with this six element of compensator can be well can be compensated for balance unity power factor load at the supply system and which can be just represented as a equivalent to a source impedance on per phase basis with equivalent to a star.

I mean you can call it the three-phase four-wire star connection and per phase basis with a neutral line to neutral and the equivalent conductance after power factor correction and load balancing and it can be converted to like a G Y.

And of course, if you want to have in place of power factor correction, you want voltage regulation; then, you can take another compensator of j B cV which is responsible for voltaging voltage regulating the load terminal equal to the supply voltage like [FL] this is a network. Now, this network, we have to find out the these compensating all six elements for different conditions. [FL] we like to discuss the analysis of this and find out the value of that is the what we call it the design like I mean.

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The load currents in terms of load admittances are as follows,

$$I_a = (G_a + jB_a)V_p,\ I_b = (G_b + jB_b)\,a^2V_p,\ I_c = (G_c + jB_c)\,aV_p \quad (35)$$

Symmetrical components of these line currents of unbalanced four-wire load are as follows,

$$I_0 = (I_a + I_b + I_c)/\sqrt{3},\ I_1 = (I_a + aI_b + a^2I_c)/\sqrt{3},\ I_2 = (I_a + a^2I_b + aI_c)/\sqrt{3} \quad (36)$$

$$I_0 = \{(G_a + a^2G_b + aG_c) + j(B_a + a^2B_b + aB_c)\}V_p/\sqrt{3} \quad (37)$$

$$I_1 = \{(G_a + G_b + G_{ca}) + j(B_a + B_b + B_c)\}V_p/\sqrt{3} \quad (38)$$

$$I_2 = \{(G_a + aG_b + a^2G_c) + j(B_a + aB_b + a^2B_c)\}V_p/\sqrt{3} \quad (39)$$

Similarly, zero, positive and negative symmetrical components of line currents of star connected compensator, is as follows,

$$I_{0cy} = (I_{acy} + I_{bcy} + I_{ccy})/\sqrt{3} = \{j(B_{acy} + a^2B_{bcy} + aB_{ccy})\}V_p/\sqrt{3} \quad (40)$$

$$I_{1cy} = (I_{acy} + aI_{bcy} + a^2I_{ccy})/\sqrt{3} = \{j(B_{acy} + B_{bcy} + B_{ccy})\}V_p/\sqrt{3} \quad (41)$$

$$I_{2cy} = (I_{acy} + aI_{bcy} + a^2I_{ccy})/\sqrt{3} = \{j(B_{acy} + aB_{bcy} + a^2B_{ccy})\}V_p/\sqrt{3} \quad (42)$$

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Well, now the load current in terms of load admittance can be expressed as follows. I mean a phase current I a can be written as a G a plus j a j B into V P that is a load, you can call it the admittance multiplied the phase voltage. Similarly, for b phase I mean G b plus j B b a square V P that is virtually for 240 degree phase shift of the voltage for b phase and c phase current can be represented again G c plus j B c and with the operator of 120 V a into V p.

Well, these are the three-phase currents. These can be unbalance reactive current or non-unity power factor current; but we are considering here of course, the typically the sinusoidal balance supply voltage.

Well, the symmetrical component of these line current of unbalanced four-wire load are as follows which can be written as a zero sequence current equal to I a plus I b plus I c by root 3 and this I 1 positive sequence current can be written of the load current I a plus a I b plus a I a square I c divide by root 3 and I 2 negative sequence current can be written as a I a plus a square I b plus a I c divide by root 3.

Well, these if you put the value of I mean from equation 35 of I a, I b, I c in these equation of positive sequence current of I, zero sequence current of I 0 and positive sequence current I 1 and I 2. [FL] I 0 can be written directly G a plus a square G b plus a G c, well from above relation and plus j B a plus a square V b B b plus a B b with a close parenthesis into V P by root 3. Similarly, I 1 can be written equal to G a plus G b plus G c plus j a B a B b plus B c divide into root 3 V P by root 3 ok.

And I 2 can be written G a plus a square G b plus a G c plus j B B a plus a square a B b plus a square V b B c and V P by root 3. [FL] these are the three symmetrical component of the load current ok; positive zero sequence, positive sequence current, negative.

Similarly, zero, positive and negative sequence symmetrical component of the line current of star connected compensator are as follows I 0cy equal to typically in terms of again compensator current of a I acy plus I bcy plus I ccy divide by root 3 and we can keep the value of these component because compensator are lossless, that is why it is represented only the your susceptances. [FL] it can be j can be taken out [FL] it will B acy plus a square bcy plus a B ccy with the V P divide by root 3.

Similarly, positive sequence current of this your star connected compensator can be equal to c denotes here for compensator. [FL] it can be I acy plus a I bcy plus a square I cy divide by root 3, which can be equated equal to j into B acy plus B bcy plus B ccy into V P by root 3 and I 2cy can be written again in the similar manner. I acy plus a square I c bcy plus a ccy by root 3 and which can be equated in terms of parameter equal to j B acy and a bcy plus a square B ccy into V P by root 3.

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The zero, positive and negative symmetrical components of line currents of delta connected compensator, is as follows,

$$I_{0cD} = (I_{acD} + I_{bcD} + I_{ccD})/\sqrt{3} = 0 \quad (43)$$

$$I_{1cD} = (I_{acD} + aI_{bcD} + a^2 I_{ccD})/\sqrt{3} = \{j(B_{abcD} + B_{bccD} + B_{cacD})\}\sqrt{3}V_P \quad (44)$$

$$I_{2cD} = (I_{acD} + aI_{bcD} + a^2 I_{ccD})/\sqrt{3} = \{-j(a^2 B_{abcD} + B_{bccD} + aB_{cacD})\}\sqrt{3}V_p \quad (45)$$

With the **use of six elements lossless compensator** (three elements connected in star, Y and other three connected in delta, D configuration) across the load, **the negative and zero sequence components of the load currents are to be eliminated and the power factor at the load bus is to be improved to unity**. It results in balanced sinusoidal unity power supply currents.

For this purpose, it must satisfy following conditions.

1. The sum of real parts of negative sequence components of load currents and compensator currents must be zero as,

   $$\text{Real}(I_2) + \text{Real}(I_{2cY}) + \text{Real}(I_{2cD}) = 0 \quad (46)$$

Well, similarly the zero sequence, positive sequence and negative sequence symmetrical component of the line current of delta connected compensator can be also written as follows. [FL] I 0 I 0cD means zero sequence current of the delta connected compensator can be written as I acD plus I bcD plus I cD divide by root 3 equal to 0 because there is no connection of delta connection to the neutral.

[FL] certainly, zero sequence current from the delta compensator cannot flow and then, positive sequence current I 1cD equal to I acD plus a square I bcD plus a square I ccD divide by root 3 and it can be written in the again lossless component, I mean which are shown in the circuit j V abcD V bccD plus V cacD into V P by root 3 and I 2cD equal to I acD a I cD plus a I square I c should divide by root 3 and you can keep the value of typically of this current in some of the your susceptances.

[FL] j it can be taken out and in bracket a square B abcD plus B bccD and plus a (Refer Time: 8:10) into V P by root 3. [FL], well with the use of six element lossless compensator, three connected in star and other three connected in delta configuration across the load, negative and zero sequence component of load current are to be eliminated and the power factor at the load bus is to be improved to unity.

And it results in a sinusoidal unity power factor supply current. [FL] for this purpose, it must satisfy the following condition. The first condition is sum of the real parts of negative sequence component of load current and compensator current must be zero; means the negative sequence component of your load current should be compensated by negative sequence current of real part of the both the compensator.

[FL] real I 2, that is load negative sequence current real component plus the star connected compensator real I 2cY and real part of this I 2cD so must be equal to 0.

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$$\text{Real}[\{(G_a+aG_b+a^2G_c)+j(B_a+aB_b+a^2B_c)\}V_p/\sqrt{3}]+\text{Real}[\{j(B_{acy}+aB_{bcy}+a^2B_{ccy})\}V_p/\sqrt{3}]+\text{Real}[\{-j(a^2B_{abcD}+B_{bccD}+aB_{cacD})\}\sqrt{3}V_p]=0 \quad (47)$$

2. The sum of imaginary parts of negative sequence components of load currents and compensator currents must be zero as

$$\text{Imag}\,(I_2)+\text{Imag}\,(I_{2cY})+\text{Imag}\,(I_{2cD})=0 \quad (48)$$

or

$$\text{Imag}\,[\{(G_a+aG_b+a^2G_c)+j(B_a+aB_b+a^2B_c)\}V_p/\sqrt{3}]+ \text{Imag}\,[\{j(B_{acy}+aB_{bcy}+a^2B_{ccy})\}V_p/\sqrt{3}]+ \text{Imag}\,\{-j(a^2B_{abcD}+B_{bccD}+aB_{cacD})\}\sqrt{3}V_p]=0 \quad (49)$$

3. The sum of real parts of zero sequence components of load currents and compensator currents must be zero. In this case, delta connected elements of the compensator do not contribute as there is no flow of zero sequence current in the delta connected network. This condition results in an equation as follows,

$$\text{Real}\,(I_0)+\text{Real}\,(I_{0cY})=0 \quad (50)$$

[FL] that is the one condition and we can keep the value of this, I mean this is the value after keeping all these load, I mean conductance load susceptances and the typically susceptances of the you can call it the star compensator and delta connected compensator.

Because they have only the susceptance, they do not have a really conductances because it is a lossless compensators so like I mean. [FL] real part should be equal to 0, [FL] we can get this equation, one equation from here. I mean and you can eliminate the voltage term from both the side, [FL] it become simplified equation.

Similarly, the second condition if the sum of the imaginary part of negative sequence current of load current and compensator currents must be zero. [FL] similarly, we can have a imaginary part of I 2 of load current plus imaginary part of star connected compensator I 2cY plus imaginary component of your delta connected compensator I 2cD equal to 0. [FL] we get the again we can put the value of I 2 and I 2cY and I 2cD into it and then, imaginary part of it can be made equal to 0. [FL] that is another condition we get it.

And the another condition is the sum of real part of zero sequence component of load current and compensator current must be zero. In this case, delta connected elements of the compensator do not contribute as there is no flow of the zero sequence current in the delta connected network. [FL] this condition results in an equation as follows.

Real part of I 0 that is a load current zero sequence current plus real part of I 0cY that is a star connected compensator which can have a typically the you can call it zero sequence current because it is connected in star with the neutral, and this should be 0. Since, there is no connection of the delta network with the delta compensator with the neutral, [FL] that term will not be there in that case like I mean.

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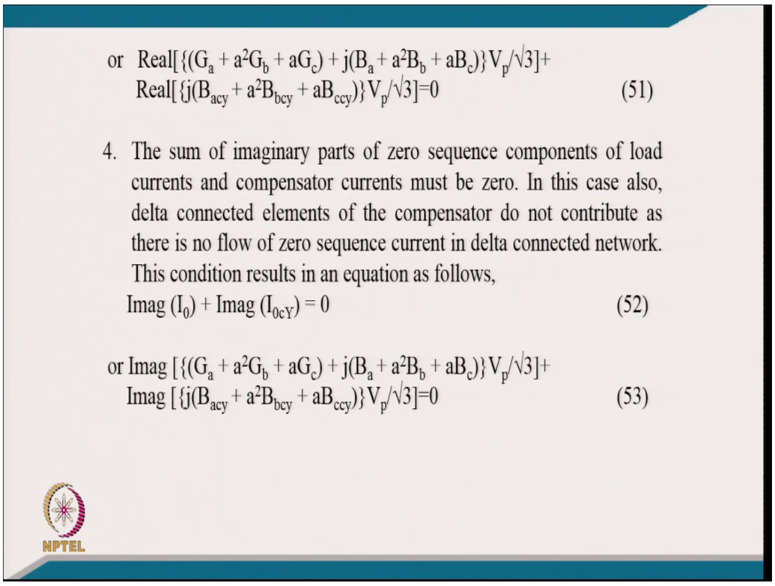

[FL] that is a another condition and you can keep the value of this and you can get the equation between load, you can call it the admittances and the star connected susceptances like. The fourth condition of course the sum of imaginary part of zero sequence current of load current and compensator current must be zero. In this case also, the delta connected elements of the compensator do not contribute and there is no flow of zero sequence current in delta connected network of the compensator.

[FL] this condition results in an equation again, imaginary part of I 0 that is load current zero sequence current plus I imaginary that is a imaginary part of your star current compensator I 0cY must be equal to 0 and we keep the value of these two currents in terms of the voltage; I mean the phase voltage and the parameters of the load like conductance of the load and typically, susceptance of the load and then, the star connected compensator, [FL] we get this fourth condition.

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5. For unity power factor at ac mains, Imaginary parts of positive sequence components of load currents and compensator currents must cancel each other ;

$$\text{Imag}(I_1) + \text{Imag}(I_{1cY}) + \text{Imag}(I_{1cD}) = 0 \quad (54)$$

$$\text{Or Imag}\,[\{(G_a + G_b + G_{ca}) + j(B_a + B_b + B_c)\}V_p/\sqrt{3}] + \text{Imag}\,[\{j(B_{acy} + B_{bcy} + B_{ccy})\}V_p/\sqrt{3}] + \text{Imag}\,[\{j(B_{abcD} + B_{bccD} + B_{cacD})\}\sqrt{3}V_P] = 0 \quad (55)$$

These five conditions have infinite solutions because there are six unknowns (susceptances of the Y-connected and the D-connected parts of the compensator) with five equations. An additional condition together with the above five equations may offer a unique solution.

There is an another fifth condition for unity power factor at ac mains, imaginary part of positive sequence component of load current and compensator current must cancel each other.

[FL] imaginary part of I 1 plus your imaginary part of I c1 that is star connected compensator a positive sequence current and imaginary part of I cD delta connected compensator, you can call it the imaginary part must they must be 0 and you can keep the value of this in terms of load conductance loss of preferences plus the star connected susceptances as well as the delta connect compensator-compensator, [FL] you get another equation.

Well, these five condition have a infinite solution because there are six unknown; susceptances of three susceptances of star connected compensator and three susceptances of your delta connected compensator and we have only the five equation. [FL] additional condition together with the above five equation may offer a unique solution means you can get a solution definite solution like.

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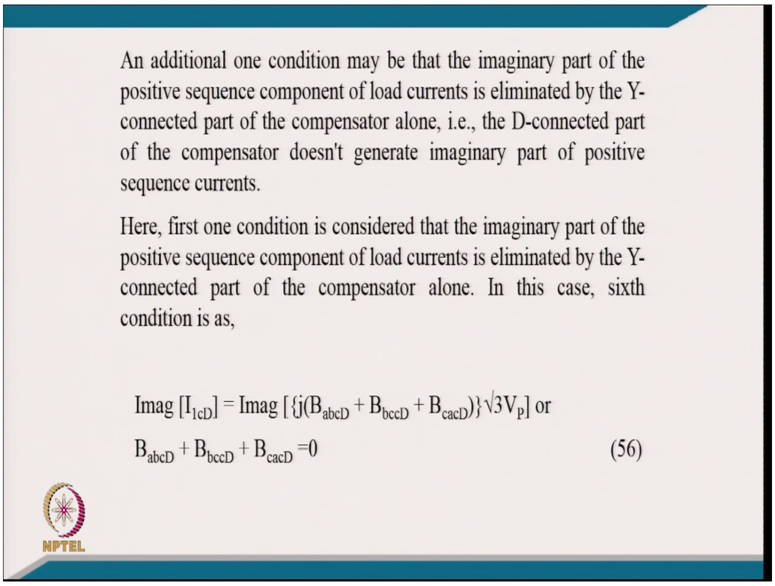

[FL], for this purpose, the sixth condition have to be added here, I mean like typically then only you can get the solution of this design. [FL] additional an additional an example I mean here we like to include couple of examples and but you may have a many such other conditions also.

An additional one condition may be that the imaginary part of the positive sequence component of load current is eliminated by the star connected part of the compensator alone, [FL] delta connected part of compensator does not generate imaginary part of the positive sequence current.

[FL] hence, the first condition is considered for the imaginary part of the positive sequence component of load current is eliminated by star connected; otherwise compensator alone in this case, sixth condition is the imaginary part of you can call it the your positive sequence delta connected compensator I 1cD should be that is equal to let us say imaginary you can keep the value of this j in terms of susceptances B abcD plus B bccD plus B cacD V P divide by root 3 that should be equal to this give you a condition your all three susceptances, sum of all three susceptances of delta connected network should be equal to 0.

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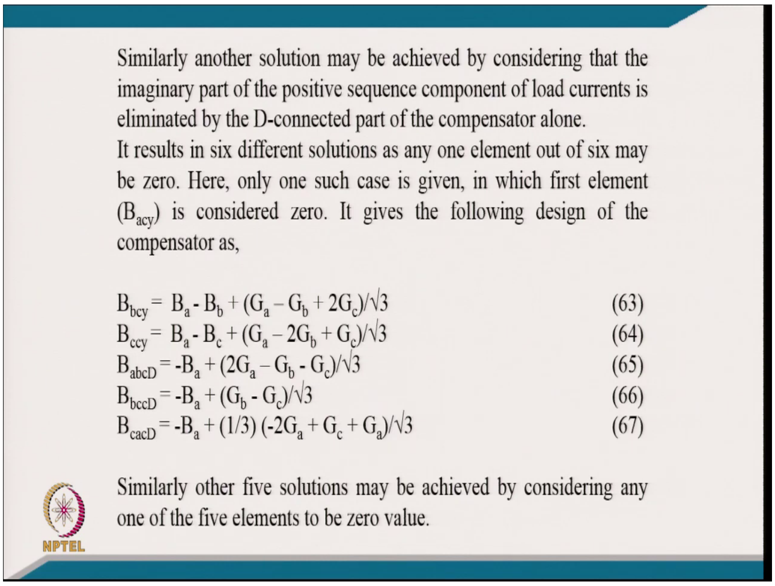

[FL], this is the sixth condition and we already have a five condition. [FL] the solution of six equation, I mean which already mention the five condition and this sixth condition give the susceptances of your star connected part and delta connected part of the compensator in terms of conductance and susceptance of the four-wire load and these values are the all five, six compensator elements in terms of the load conductance and load susceptances.

[FL] you get the design for this particular, one particular solution and you can called these six lossless passive element connected in star and delta configuration across the four-wire load are expected to result in unity power factor balance supply current like. [FL] that is the one solution you can call it with the sixth condition added.

Similarly, we can have another solution may be achieved by considering that the imaginary part of the positive sequence component of load current is eliminated by delta connected part of compensator alone. So, it results on six different solution as any one of the element of six may be 0. Hence, one of the such case is given in which the first element Bayc is considered zero.

It give the following design equation. [FL] we consider the susceptances of a phase a star connected network is 0. [FL] it give the following design of the compensator for all elements of compensator in terms of load susceptances and load conductance, [FL] that is a another solution of value of five element. [FL] similarly, other five solution may be achieved by considering any one of the five elements of the compensator to be 0, [FL] you will have certainly in that manner typically the six solution like I mean also.

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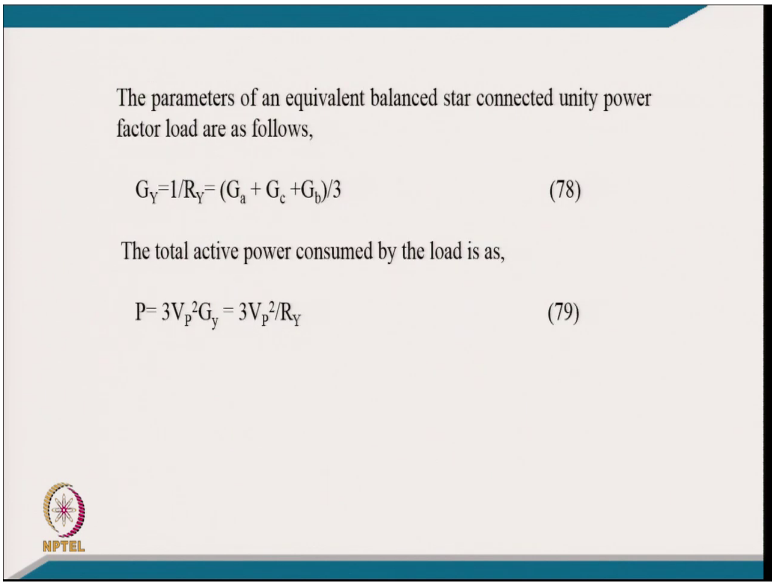

Well, the after the compensation, I mean by anyone condition you find the parameter of equivalent balanced star connected unity power factor load are as follows.

[FL] conductance in equivalent load balanced unity power factor load, I mean after the putting the compensator you will get a G Y equal to 1 upon R y equal to G a plus G b, G c plus G b by 3 and the total active power consumed by the load is as P equal to 3 P V P square G y because V P is a per phase voltage and G y is the per phase conductance and you can just put this equal to 3 V P square by R Y.

[FL] that is the power consumed by the total load may be unbalanced load or even a it can be single-phase load or two-phase load. [FL] all conditions of three-phase four-wire be can be covered in the these, I mean like solutions like.

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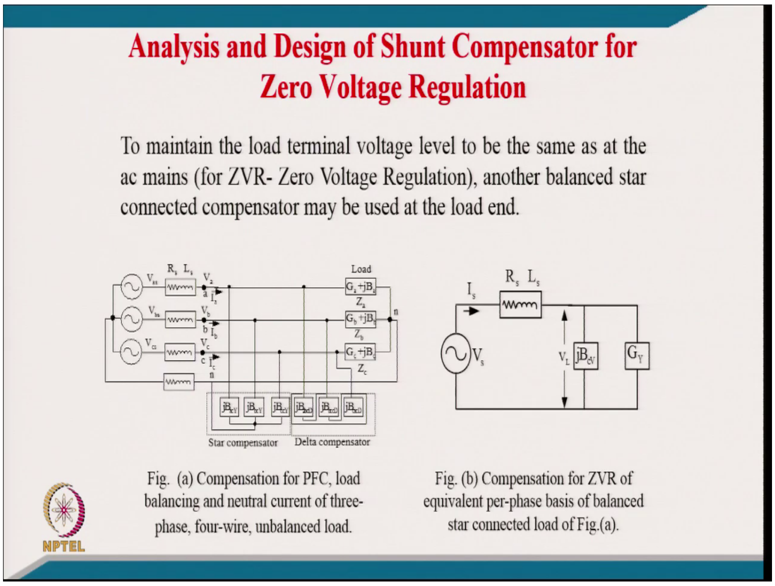

[FL] well, [FL] we have to extend this solution like analysis design of the shunt compensator for zero voltage regulation because in previous section, we consider it typically for unity power factor condition. [FL] for zero voltage regulation to maintain the load terminal voltage to be the same as the ac mains for zero voltage regulation, another balanced star connected compensator may be used at the load end.

[FL] after this, I mean the entire four-wire network with six compensator which we can get a unique solution which already we discuss it that can be have a balanced star connected per phase load, this is a source impedance and G Y which we discuss in previous section.

And now, because that was for unity power factor operation, now we want to get for voltage regulation. [FL] we have to put another typical compensating element for all the three-phase. It is a given a unique solution for per phase here, [FL] we have to put another compensator for voltage regulation j B cV in parallel to the load of unity power factor balanced load like and we have to find out this value of the B cV in addition to all six element value which we already calculated like.

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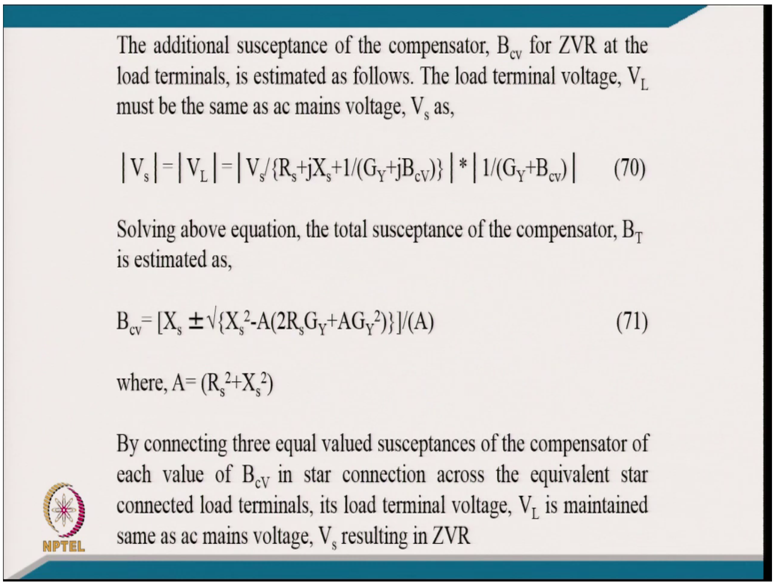

[FL] the additional susceptances of the compensator B cy for zero sequence zero voltage regulation at the load terminal is estimated as follow. The load terminal voltage must be the same as the ac terminal supply voltage, mains voltage. [FL] V s magnitude equal to V L and you can put the value of the typically here the V L.

[FL] it is the total you can call it the current, I mean the net current at the source side V s divide by R s plus j s source impedance plus the load impedance one upon G Y plus j B cV including the compensator impedance in parallel with the conductance of the unity power factor load. [FL] this is a current multiplied the your impedance of the your total load along with the compensator 1 upon G Y plus G B cv I mean like.

[FL] solving the above equation, the total susceptance of the compensator B T can be calculated in a manner that B cv equal to X s source impedance plus minus under root X square into a in bracket 2 R s G Y plus A square G Y bracket close divide by A; where, A is a R s square plus X s square, typically I mean from the source impedance.

By connecting three equal valued of susceptances of the compensator of the each value of B cV in star connection across the equivalent star connected load terminal, its load terminal voltage is maintained same as the ac source resulting in zero voltage regulation like I mean.

[FL], we already discuss the basic formulation in the previous class. I mean the derivations that how this compensation for power factor and typically, in case or voltage regulation in case of single-phase and in three-phase three-wire system, we have included the load balancing also because in three-wire system, the load can be unbalance along with the reactive power requirement and of course, we discussed even in single phase, the reactive power compensation of the load ac single-phase load can be either for power factor correction or voltage regulation.

These two conditions cannot be met simultaneously. [FL] you have to consider only one condition out of two.

But in three-wire system, then we can have it even the load balancing also, again along with these two conditions. When we come to like a three-phase four-wire system because of load unbalancing on three-phase four-wire system because load can be connected between single-phase and neutral, [FL] you might have a only single-phase load connected between line to neutral or maybe two-phase between again another line to neutral and third-phase also between third-phase and neutral.

[FL] even if you have a single-phase load or two-phase load, maybe unbalanced load of three-phase, you will certainly have a numeric this neutral current. [FL] we certainly can have a in three-phase four-wire which we discussed in basically mathematical formulation that we can eliminate the neutral current also.

[FL] any unbalanced load, I mean in three-phase four-wire or three-phase three-wire can be realized as a balance load, as a power unity power factor load by this lossless passive element. I mean we all gone all the time discuss that we should use the lossless passive element; in the sense, that we should be able to use only the inductor and capacitors for providing the function of reactive power as well as load balancing and neutral current elimination.

[FL] today, we will like to discuss I means the numerical example to demonstrate all these features which we develop the mathematical formulation with proper circuit in the previous part of the lecture like

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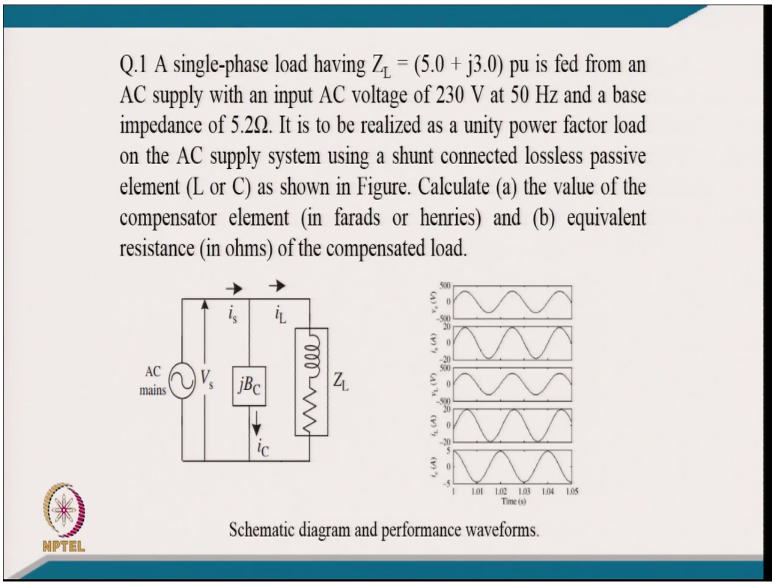

[FL], let us come to the typically the first numerical examples, I mean which is on the power factor correction of single-phase like I mean. [FL] the if you look into the problem, it is a single-phase having a load having a the load impedance of 5.0 plus j 3.0 per unit.

It fed from is your an AC supply to the input voltage of 230 Volt 50 Hertz and base impedance of 5.2 Ohm and it is realized as a unity power factor load on the supply system using a shunt connected lossless passive element; may be the I mean inductor or capacitor as shown in the figure and calculate the value of compensator element.

Again, it can be if it is a capacitor, it will be in Farad on micro Farad or if it is a inductance, it can be in Henry or milli Henry and then, after compensation, what is the equivalent resistance of the compensated load because it is to be compensated to unity power factor load after this I mean you can call it like a typically the combination of both, as you can see here in the typically in the waveform like I mean or so.

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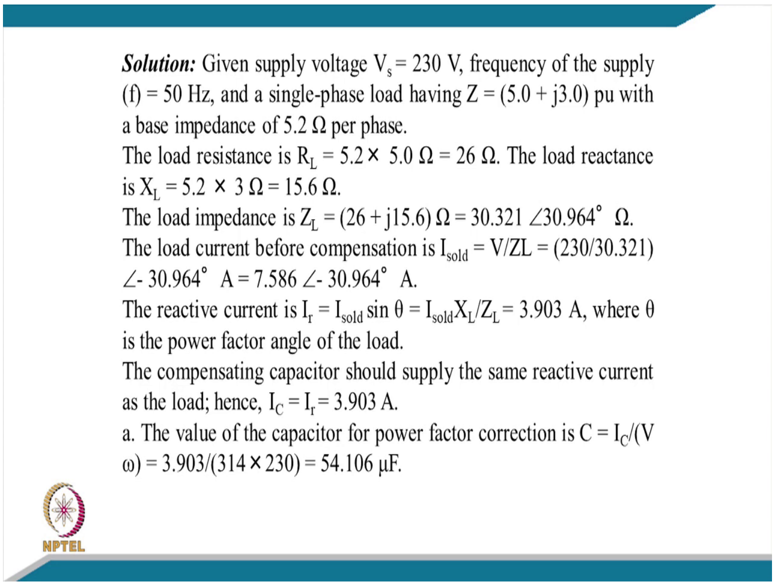

[FL] well, coming to the solution of this problem, I mean in the next slide, [FL] we can say the there is of course supply voltage given in the numerical problem 230 Volt and frequency is 50 Hertz and we have a single-phase load of again 5.0 and 3.0 per unit with the base impedance of 5.2 Ohm per phase.

[FL] we can calculate the actual value because it is given in per unit; in of course, in power system, we I mean or even a like a electric power system, we consider all with the per unit system. [FL] you must have a idea of per unit system. [FL] certainly, to get a actual value, we have to multiplied it by base impedance.

[FL] if it is a like a 5 typically Ohm, [FL] it had to be multiplied by base impedance [FL], then you will get actual Ohmic value of the load like a resistance is 26 Ohm and load reactance which is again 3 Ohm multiplied the base impedance of 5.2, it comes 15.6 Ohm.

[FL] load impedance in like in terms of Ohm, now becomes like your 26 plus j 15.6 Ohm and 26 is the resistance and 15.6 is the reactance of the load and you can convert this your rectangular coordinate impedance into the polar coordinate; means, 30.321 Ohm at the angle of 30.964 degree, [FL] that is the load impedance we have.

Now, this load impedance which is connected to the source, we have to now calculate the compensating element in shunt of with that so that power factor correction is made unity and typically, you can call it is behave like a resistive load. [FL] load current before the compensation, we can call it V upon Z L and that is 230 upon 30.06, [FL] at the angle because Z L has angle, [FL] when it will go the angle above, it will become minus angle.

[FL] you will have a current typically 7.586 at the angle of minus 30.964 degree Ampere like. [FL] out of that, we can find out the reactive current; I mean that will be I s old into sin theta or it can be I s old X L upon Z L and this will come like 3.903 Ampere, where theta is the power factor angle of the load which is given in the impedance also.

The compensating capacitor now should supply the same reactive power of the load. Hence, I c that is a compensating current should be equal to reactive current of the load that is 3.9 point 903 Ampere. [FL] value of the capacitor for power factor correction because it is a because load is inductive.

[FL] I mean the compensator should be capacitive, [FL] it will be C equal to I c upon virtually the V omegas because omega C equal to here you can call it like V omega C equal to I c, [FL] C you can calculate from I c upon V omega. [FL] we can keep the value of this like let say I c 3.903 divide by I mean omega here for 50 Hertz into 2 phi f that is 314 into 240, [FL] it comes like a 54.106 microfarad like I mean. [FL] that is a if that much capacitor we connect in parallel, then certainly, we get a unity power factor load.

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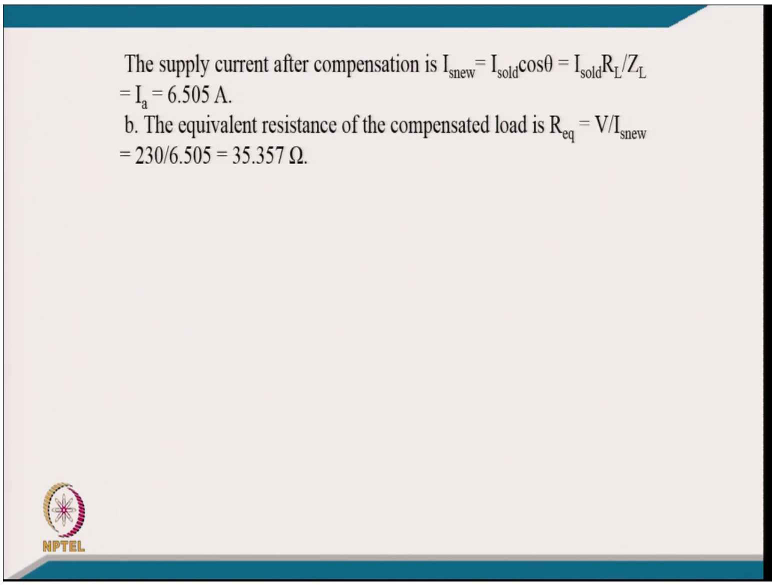

Now, we can find out what is the supply current after the compensation that will be I s new, I s old into cos theta that is only now the resistive circuit I s old R L upon Z L and that is equal to I a 6.505 Ohm and equivalent resistance of the compensated load, now we can say R equivalent V upon I s new that is 230 divide by 6.505, [FL] the equivalent load resistance will be 35.37357 Ohm. [FL] that is the solution of this typical numerical problem; I mean, it is a simple power factor correction problem by using the compensator or capacitor in parallel with the your inductive load.

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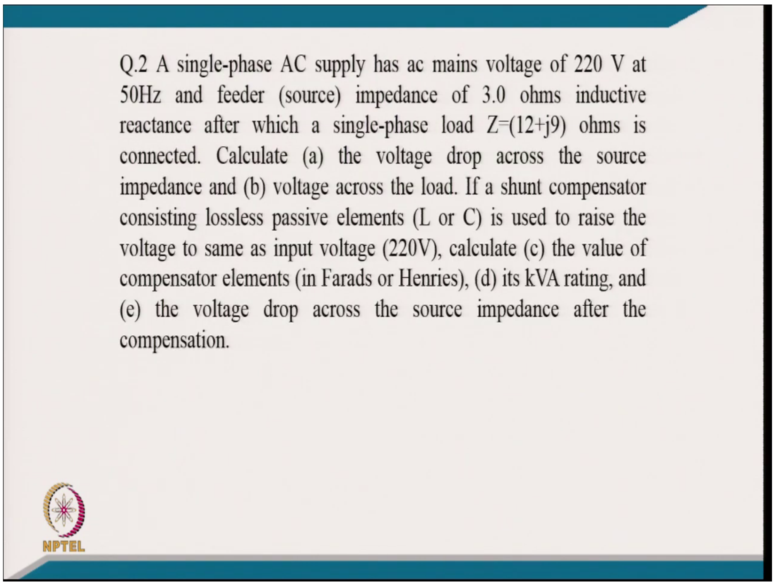

Now, coming to second problem, again on the single-phase here, a single-phase AC supply has a ac mains voltage of 220 at 50 Hertz. The feeder; here we have consider the feeder Ohm impedance of 3 Ohm inductive reactance after which a single-phase load is connected 12.9 j9 Ohms is connected.

I mean we have connected here the consider the source impedance which maybe a you can call it like a impedance leakage impedance of the even a or transformer; I mean short circuit impedance of the transformer which highly inductive and you can have a feeder inductance, [FL] we for simplicity at the moment, we have considered that there is a some impedance which include the distribution system impedance and it is a only the inductive one of 3 Ohm.

[FL] calculate the voltage drop across the source impedance, the voltage across the load. If shunt compensator consisting of passive lossless element either inductor or capacitor is used to raise the voltage at the same as the input voltage, [FL] calculate the value of compensator element either in Farad or Henry or and its kVA rating and the voltage drop across the source impedance after the compensation I mean like.

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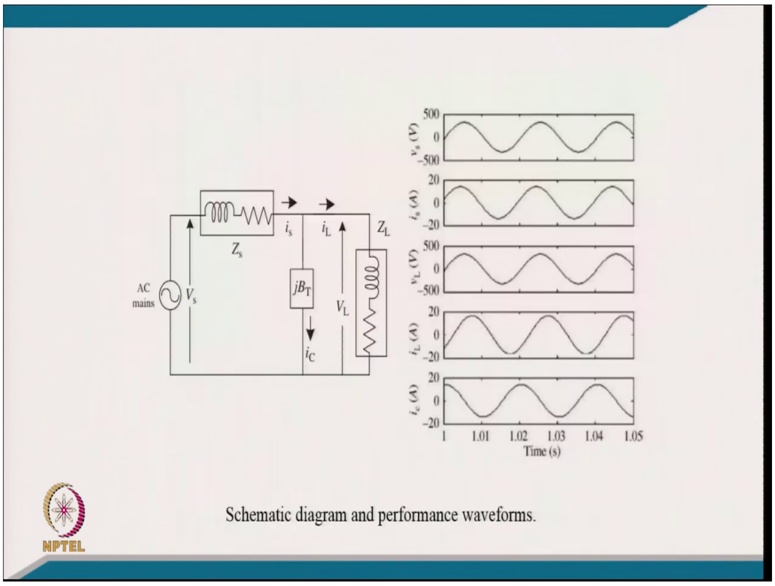

Schematic diagram and performance waveforms.

[FL] this is typically a voltage regulation problem, I mean you might have seen now we can connect this compensator if you look into here, this compensator we are connecting in parallel to the load. Now, very purpose compared to previous problem, previous problem we consider the power factor correction; here, we are considering the voltage regulation.

[FL] now, we have to find out the shunt compensator value for voltage regulation certainly, this value will be little larger than the power factor correction. The reason being that we have to take care of the drop of this source impedance also. Well of course, you can see here, I mean we put the value of course we made a this waveform for this actual data and you can see that this current I mean the source current is slightly leading than the voltage.

[FL] even the you can call it zero voltage regulation means whatever the source voltage should be equal to the load voltage that will come always little leading power factor because your source impedance is of inductive nature and that is a reason you can just see all the parameters here.

However, the compensator is capacitive, [FL] this current is typically 90 degree leading than the voltage. I mean the load is certainly it is a inductive, [FL] its lagging than the voltage. [FL] all these wave form can be give you typically the concept of I mean how this compensator will work like I mean or so.

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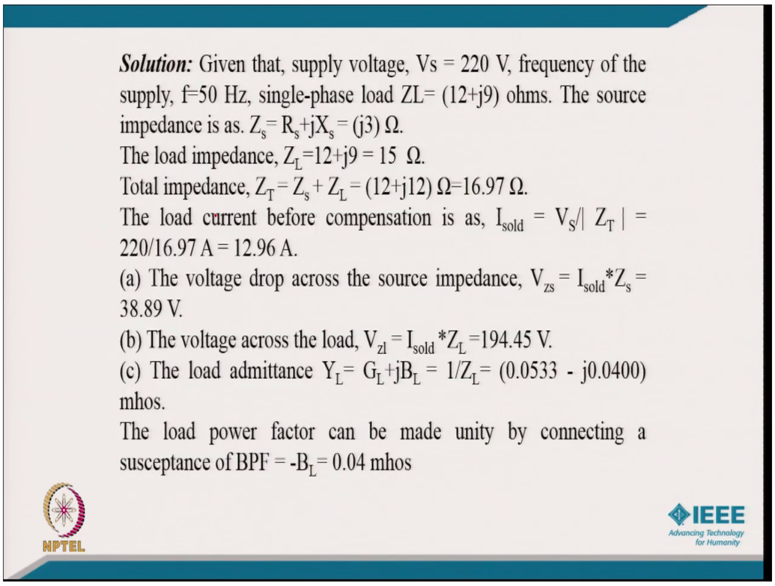

Now, coming to the numerical problems of this, I mean given the supply voltage of 220 Volt frequency of 50 Hertz and single-phase load of your 12 Ohm; 12 Ohm plus 9 Ohm and the source impedance here is your Z s equal to R s plus j X that is only R s is 0 and we took a only the inductive source impedance that is 3 Ohm for the case of simplicity to understand and the load impedance here is 12 plus I mean j 9 that comes the impedance as a 15 Ohm.

[FL] you can find out the total impedance that is Z s plus Z L and you can add in that typically of j 3 only in that. [FL] it become 12 plus j is 12, the total impedance of the circuit including the source impedance and the value comes around 16.97. [FL] now, the load current before the compensation that is we call it I s old supply old current before the compensator V T V S upon Z T. Total impedance of the circuit 220 divide by the 16.97 that comes 12.96 Ampere.

And the voltage across the source impedance now will be as I s old into Z s and that you can call it 12.96 into your 3 Ohm inductive, [FL] 3 into that will be your 38.89, [FL] that is the voltage across the source impedance and the voltage across the load, we can find out from I s old into Z L, [FL] it in place of it is 194.45 because of the source impedance.

[FL] in place of 220, we are getting the voltage across the load only 194.45. [FL] that is the remaining voltage the drop across the source impedance, [FL] that is typically. Now, let us come to the typically the another part for calculating the compensation, you can call it the compensation rating I mean compensator rating I mean which you have to keep in parallel with the load to maintain the voltage regulation.

[FL] now, we can go load admittance, I mean that is we have to keep in terms of admittance G L upon jB L 1 upon Z L and you can get the value of typically of admittance 0.0533 minus j 0.0400 I mean mho because the admittance will be always in mho and the power load power factor can be made I mean like typically unity by connecting the susceptance of this compensator for typically for power factor correction.

[FL] it will be minus B L that is around 0.04 because that is the value of typically of you can call it the load reactive part impedance.

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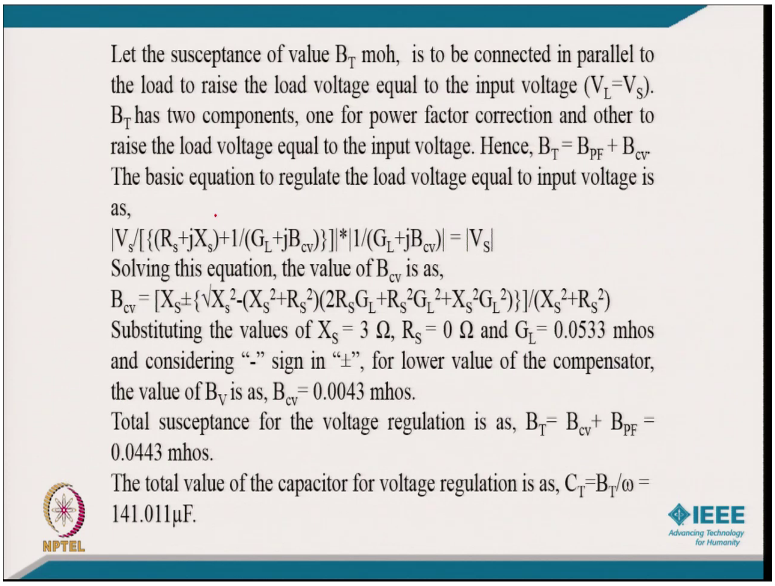

[FL] let the susceptance of the value BT in mho is to be connected in parallel to the load to raise the load voltage equal to the input voltage V L equal to V S. [FL] B T has two component, one for power factor correction and other is to raise the load voltage equal to the input voltage. Hence, the B T will be equal to B PF which we have already got it for power factor correction putting as like you can call it like a lossless element in parallel with the load for power factor another is the B cv that is for regulating the constant voltage across the load.

[FL] basic equation to regulate the load voltage equal to the input voltage is this we derived already that you are you can call it the voltage across the load which is the calculated value here equal to should be the source voltage and how we calculated this typically the load voltage?

We have calculated V S, we got the load current, the total current of the circuit multiplied the load admittance I mean load impedance, you can call it. [FL] this we got typically the voltage across the load that should be the magnitude of this should be equal to the source voltage and solving this equation, we got the B cv that is the typically you can call it the Volt compensator susceptance.

It should be X s plus minus under root X s square minus X s square R s square in bracket 2 R s G L plus R s square G L square and X s square G L square divide by X s square R s square. [FL] you can substitute the value of X s equal to 3 and R s equal to 0, then the equation become simplified and G L equal to 0.0533 and considering the minus sign in your plus minus for lower value of compensator value because lower value will only give the lower typically with this minus sign.

[FL] value B v from this relation after putting value will become B cv equal to 0.0043 mho. [FL] total susceptance for the voltage regulation at this B cv plus B PF will be 0.00 0.0, 0.0433 mho and total value of the capacitor for this voltage regulation is C T equal to B T upon omega that comes 141.00 micro Farad.

[FL] this if you put this much capacitance in parallel to this load, you will get a same voltage across the load what it is the source voltage and this will be the condition for your zero voltage regulation like I mean.

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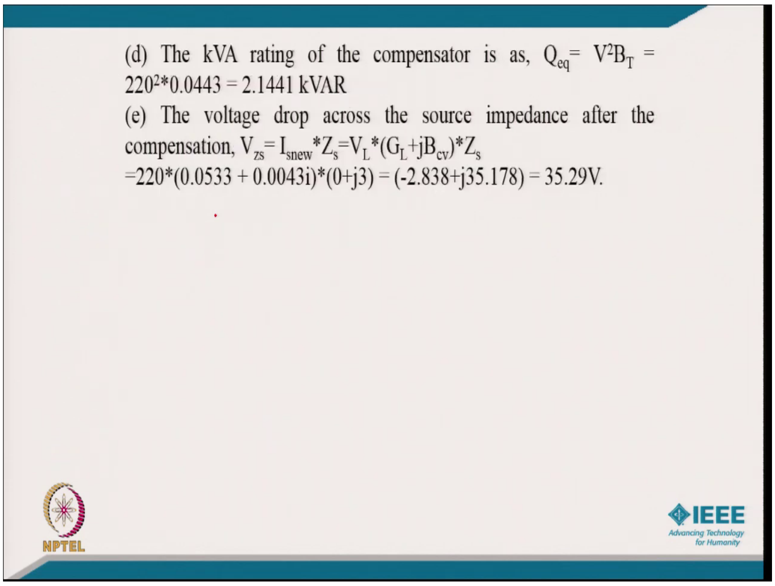

[FL] kVA rating, I have to find out for this compensator that will be V square B T and you can keep the value of V square 220 into your B 0.0443 and it comes 2.1441 kVAR. I mean that much capacitor if you connect it, then you will get a zero voltage regulation and the voltage drop across the source impedance after the compensation, we can find out I s new into Z s and that I s new will be is nothing but you can call it V L into your typically now G L plus j B v.

This is that equivalent you can call it the your admittance of the load plus compensator ok, [FL] that will be virtually the current multiplied the source impedance that is Z s. [FL] if we keep the value of it, now the drop in the source impedance will be 35.29. In spite of this drop, we will get the voltage across the load typically of order of the same as your 220 Volt like I mean or so.

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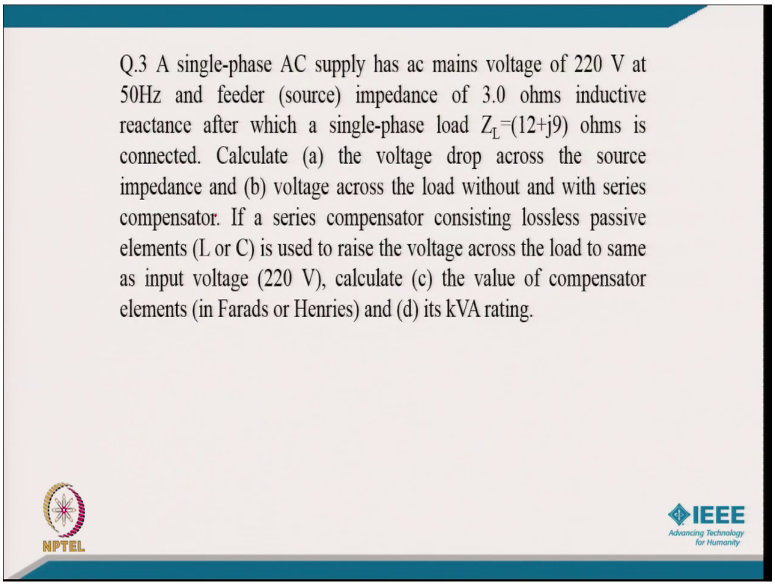

[FL] that is typically the voltage regulation problem. Now, we come to the third another problem. I mean we have all the variety of the problems, you can think about here. [FL] it is a another problem here a single-phase AC supply has the ac mains voltage of 220 at 50 Hertz and the feeders or source impedance of 3 Ohm.

Inductive reactance after which a impedance of 12 point j 9 Ohm is connected calculate the voltage drop across the source impedance, voltage drop across the load without series compensator and if this series compensator is lossless element is used to raise the voltage across the load same voltage, calculate the voltage and kVA rating like I mean.

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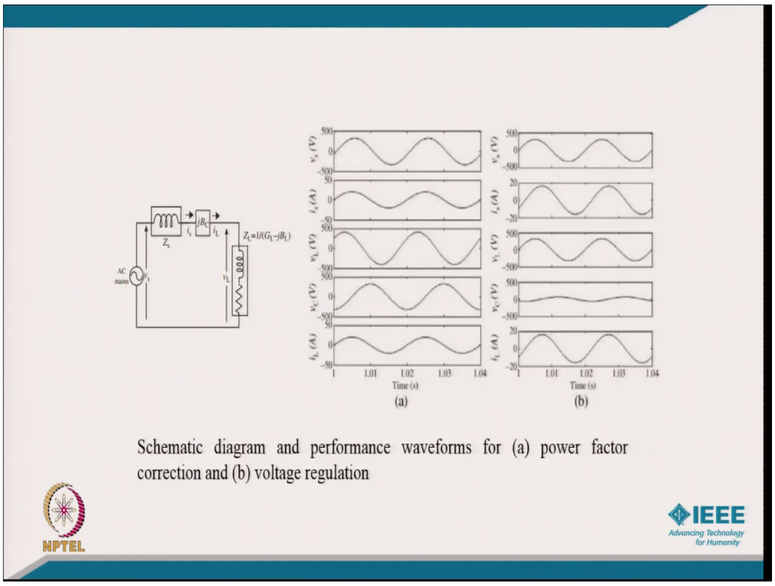

Well, in this case, we will be connecting compensator in series with the source impedance after which the load is connected and you can see the typically waveform for both the cases, for power factor correction and typically for voltage regulation both the cases I mean like.

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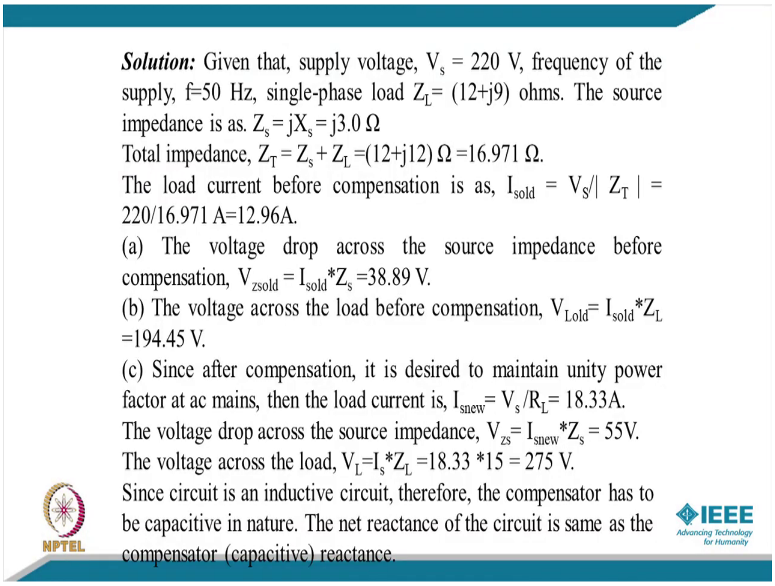

And well, we can have a like a solution here. Given that supply voltage of 220; V s equal to 220 Volt, frequency of supply of 50 Hertz and single-phase load Z L equal to 12 point plus j 9 Ohm, the source impedance is Z s equal to j s 3 Ohm. The total impedance of load is Z T equal to Z s plus j L that is 12.12 Ohm is 16.971 Ohm and load current before compensation is as a old current V s upon Z T, 220 divide by 16.971 equal to 12.96 Ampere. The voltage drop across the source impedance before the compensation is V s z equal to I s old into Z s that is 38.89 and the voltage across the load after the before the compensation is V load equal to I old Z s 194.45.

[FL] voltage across the load reduces because of the drop in source impedance and it is a power factor of the load is lag in nature. [FL] certainly, you will have a poor voltage regulation.

[FL] since after the compensation it is desired to maintain unity power factor at ac mains, then the load current is I s equal to V s upon R L that is 18.33 Ampere and voltage across the source impedance will be Z s into I s into new into Z s, [FL] that will be you can call it 18.33 into 3, that is comes 55 Volt and the Volt across the load will be your V L equal to I s Z L [FL] 18.33 into 15, it becomes 275 Volt.

[FL] you can understand here, now we put a series compensator that is the reason the voltage have gone more than typically of your 220 that has become 275. Since the circuit is an inductive circuit; therefore, the compensator have to be capacitive in nature and the net reactance of the circuit is same as the compensator or capacitive reactance like.

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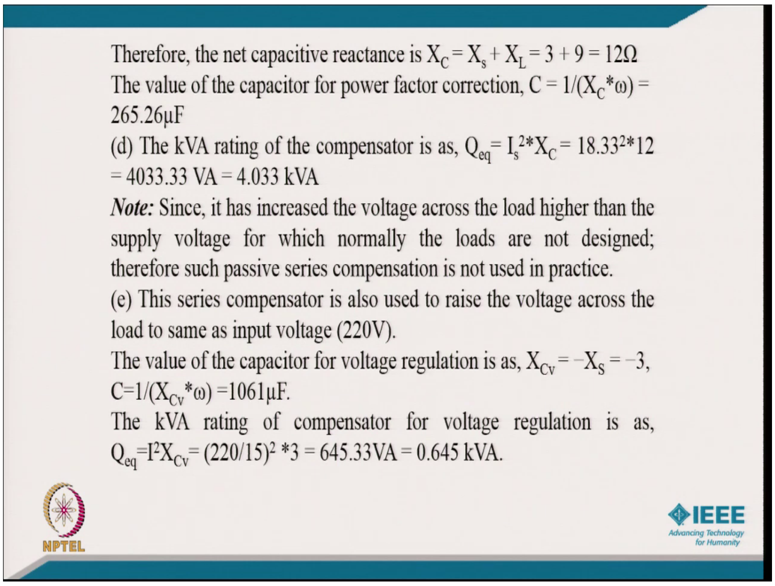

Therefore, the net capacitive reactance is X C equal to X L X s plus X L and that is typically, you can call it 3 plus 9 Ohm equal to 12 Ohm and the value of the capacitor for power factor correction is your C equal to 1 upon X C into omega, it comes 265.26 micro Farad. [FL] net kVA rating of the compensator in series, I s square X C, it comes 18.33 into 12, it comes like a 4033.33; VA equal to 4.033 kVA.

[FL] since, it has increase the voltage across the load higher than the supply voltage for which normally the load are not design. Therefore, such passive series compensation is not used in practice in distribution system. [FL] this series compensator is also used to raise the voltage, I mean that is a second another part of this numerical; the series compensator is used to raise the voltage across the load to same as the input voltage and then, we have to find out the compensator element.

[FL] that is the value of the voltage regulation is X Cv equal to minus X s equal to minus 3; [FL] C will be equal to 1 upon X Cv into omega, [FL] that is 1061 micro Farad. I mean what we are doing here; why putting this capacitor equal to source impedance? Because we have to only compensate here the drop of the source impedance.

[FL] kVA rating of the compensator rating here for voltage regulation is X Q equal to I square X Cv that is 220 divide by typically 15 Ohm square into 3 and come 645.33 V A and it comes 0.645 kVA. [FL] you can call it like a typically this compensator rating for voltage regulation is much lower than what we got in shunt compensator.

[FL] now, from this previous problem and this problem, we can conclude two things that I mean the series compensation is not good for certainly for power factor correction because voltage across the load increases much more what the load can have it. But for the voltage regulation across the load to be rated, the kVA rating of the voltage regulator here, it is much lower.

[FL] that is the reason you might see in the transmission system, we use the series capacitor because that becomes more effective as far as voltage regulation is concerned; but in you can call a distribution system, we always use the shunt compensation. [FL] that you can interpret from these two numerical by comparing the rating of these compensators like.

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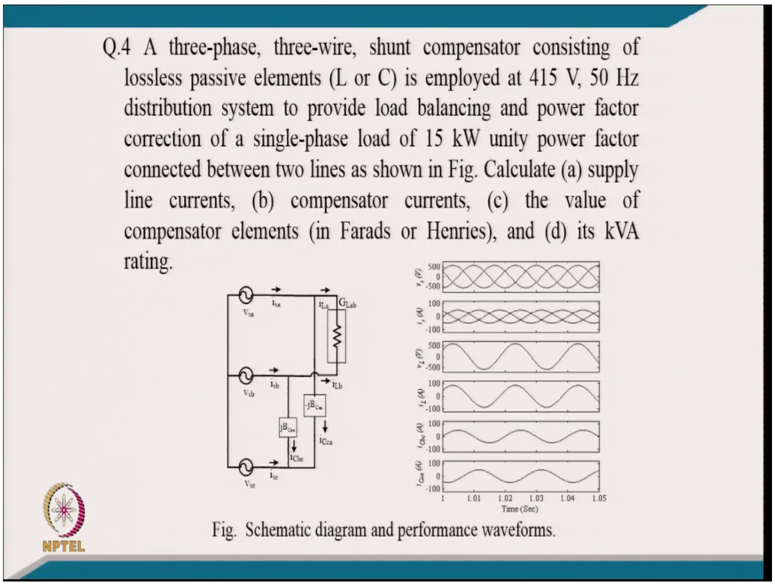

Coming to now the numerical problems on three-phase three-wire system, a three-phase three-wire shunt compensator consisting of lossless passive element is employed at 415 Volt, 50 Hertz distribution system to provide load balancing and power factor correction of a single-phase load of 15 kilo Watt unity power factor connected between two lines as shown in the figure. Calculate the supply line current, compensator current, the value of compensator element in Farad or Henry and its kVA rating.

[FL] what we can do here the load compensation which is a very interesting classical problem because such load are connected line to line like a traction system or it is even a furnaces, we use such kind of load.

[FL] providing the compensation for here, I mean making this load I have unity power factor supply system of three-wire system by lossless element of these two element, you can see just like the after calculation these value output and you can see I mean the three-phase supply current balance current and the compensator current is also given below and load current and load voltage is also given in this wave form.

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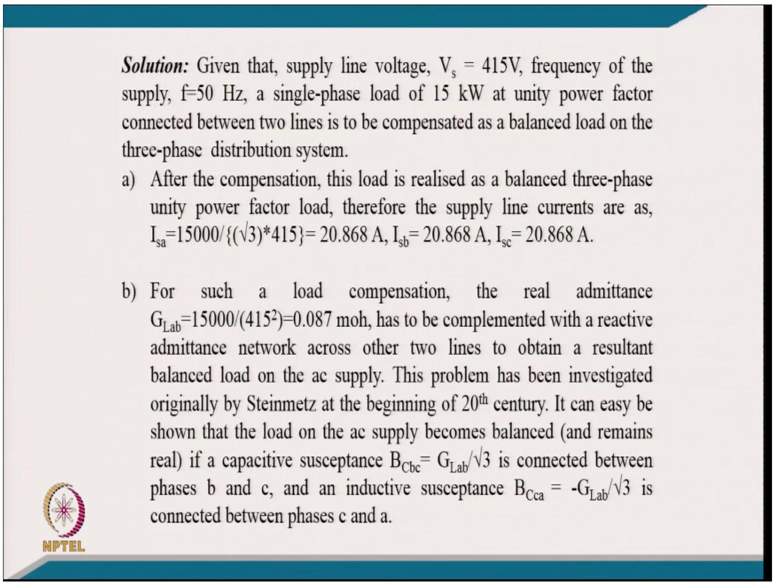

[FL] based on that, we have a now the solution to this problem given that the supply voltage V s equal to 415 Volt, frequency of supply 50 Hertz and single-phase load of 15 kilo Watt at unity power factor connected between two line to be compensated as a balanced load on the three-phase system.

After the compensation, this load lies as a balanced three-phase unity power factor load. [FL] therefore, the supply line current are as the power consumed by the load that is 15 kilo Watt or 15000 Watt divided into root 3 into 415. Why we are taking root 3? Because it is a line voltage.

[FL] it become 3 times the phase voltage; if we take a phase voltage 415 by root 3, [FL] it is a 3 time phase voltage, [FL] that is becomes a line current. [FL] it become 20.868 Ampere and all three-phase currents will be the same magnitude you can call it in because it is a balance now load balancing is there at unity power factor.

[FL] that is a equivalent load current like here and for such a load compensation, the real admittance of the load which is 15000 Watt divide by 415 square because load is connected across the line to line.

[FL] you can call it as a single-phase load connected across the 415 Volt, [FL] you get the conductance of it 0.087 mho has to be complemented with reactive admittance network across the other two line to obtain result balanced load on the ac supply and this problem has been investigated originally by Steinmetz at the beginning of 20th century.

It can be easily shown that the load on the ac supply becomes balanced and remains real, if capacitive susceptance Cbc the value of G Lab divide by root 3 is connected between phase b and c, and the inductive susceptance B Cca that is minus G Lab divide by root 3 is connected between phase c and a.

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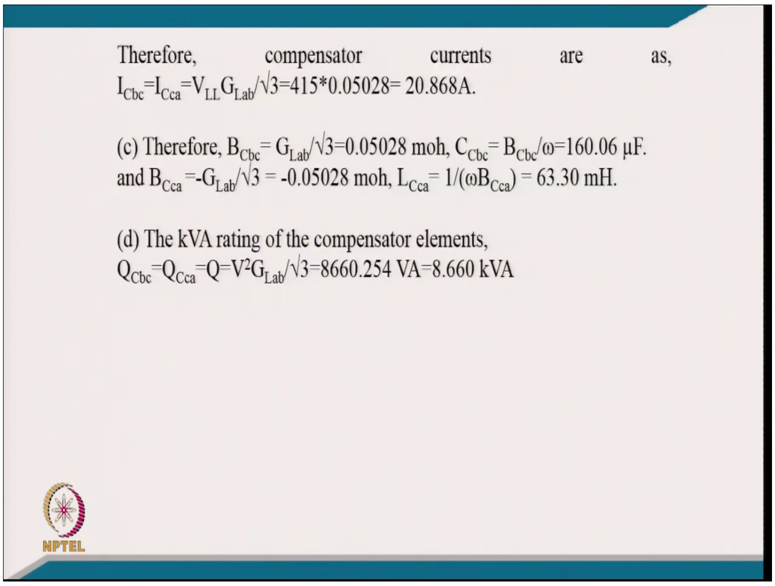

And putting the value of this, I mean we can get the value of I C compensator across the B c equal to I ca, I mean both are equal in magnitude V LL line voltage into G L divide by root 3 that is 415 into 0.0500, [FL] it comes like a current comes only 20.86 Ampere.

Therefore, the B Cb, the value of element G Lab by root 3 is 0.0528 mho and the capacitance equivalent to B Cb divide by omega, it comes 160.06 micro Farad and the another compensator which is inductive across the another line two line that is ca line because load is connected across ab, [FL] it will be G Lab divide by root 3 and minus 0.05028 mho and the inductance of this L Cca will be 1 upon omega B Cca that is 63.30 milli Henry.

And this will convert the whole network into three-phase balance supply system and you can find out the kVA rating of the compensator element will be Q Cbc and equal to Q Cb ca equal to Q V square G L upon root 3 that comes 8660.254 V A or you can call it equal to 8.66 kVA that is the compensator elements I mean rating of one element; similar rating of another element also to be connected across the another line like.

[FL] that is the we demonstrated that how a single line to line resistive load can be made equivalent balance sinusoidal unity power factor load using the lossless element only means inductor and capacitors like I mean or so.

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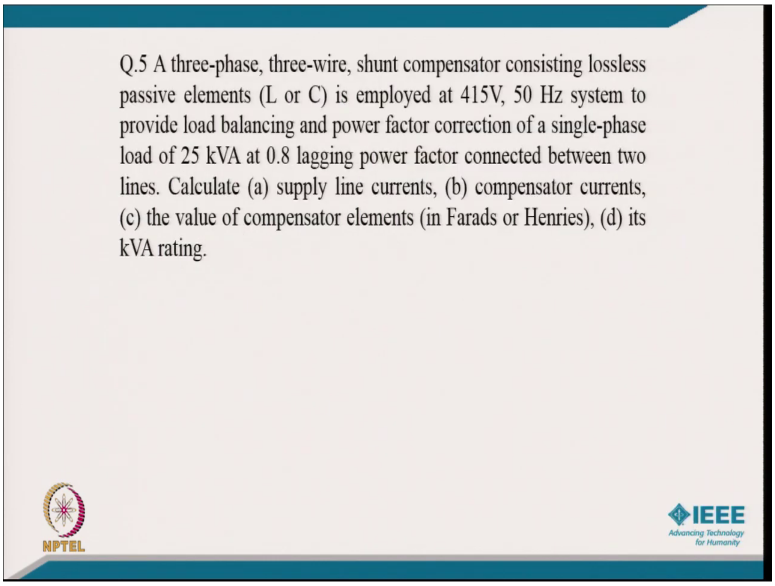

Coming to typically another three a three-phase three-wire shunt compensator consisting of lossless passive element is employed at 415 Volt, 50 Hertz system to provide load balancing and power factor correction of a single-phase load of 25 kVA at 0.8 lagging power factor connected between the two line. Calculate the supply line current, compensator current, the V A value of the compensator elements Farad and Henry and its kVA rating.

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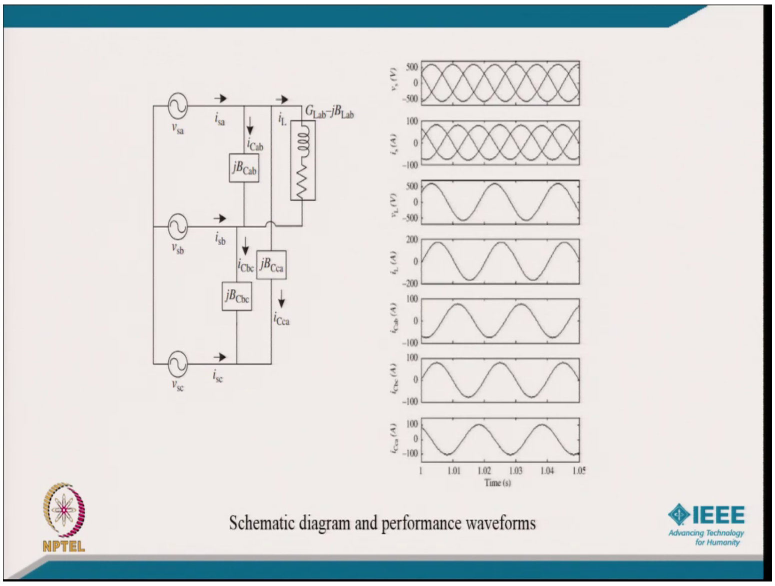

Well, the you can call it now compared to previous one, I mean we have to connect another compensator, [FL] for power factor correction, make it the line to line load of line a b of equivalent to a resistive load and then, remaining element comes in the similar manner as we did in the previous numerical problem.

These are after putting composition, the real wave form of this numerical problem you can see and current all three-phase currents or line currents are in phase with the voltage like I mean and you can see the all voltage and current of the compensator like I mean or so.

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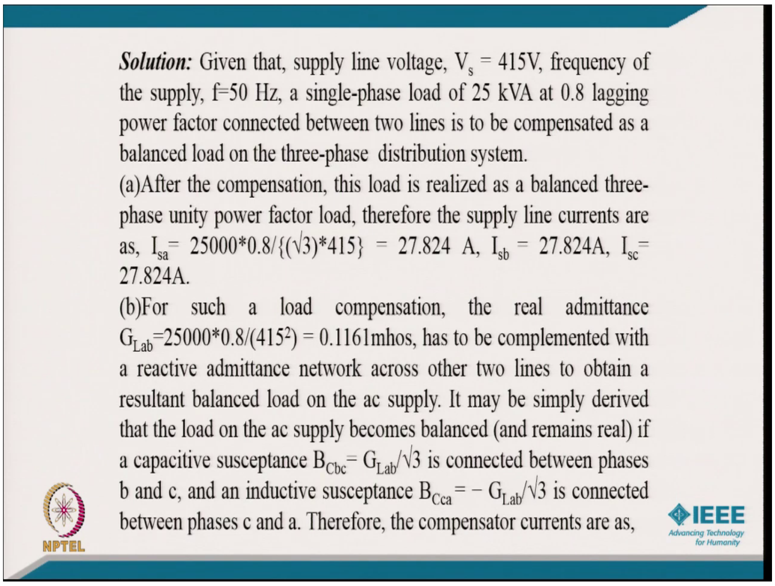

[FL] coming to the solution of is given that the supply line voltage is 415 Volt, frequency of supply 50 Hertz and single-phase load of 25 kVA at 0.8 lagging, power factor connected between the two line to be compensated as a balanced load on the three-phase distribution system.

[FL] after the compensation this load is realized as a balanced three-phase unity power factor load. Therefore, line current will be I sa equal to we have to calculate the power, [FL] it is 25 kVA at 0.8 power factor [FL] that a real power will be 25000 into 0.8 divide by root 3 into 415, [FL] current comes 27.824.

And these balance current of unity power factor will flow in all the three-phases and for such a load compensation, the real admittance we can find out of from this real power 25000 into 0.8 divide by 415 square, [FL] it comes 0.116 mho had to be complemented with the reactive admittance network across the two other lines to obtain the resultant balanced load on the supply.

It may be simply derived that the load on the ac supply becomes balanced and remain real. If capacitive susceptance of this B c equal to G Lab by root 3 is connected between the line P b, c and a inductive susceptance of B Cca minus G Lab divide by root 3, its connected between the phases c and a; therefore, the compensator currents are as I Cab equal to Q Lab divide by V.

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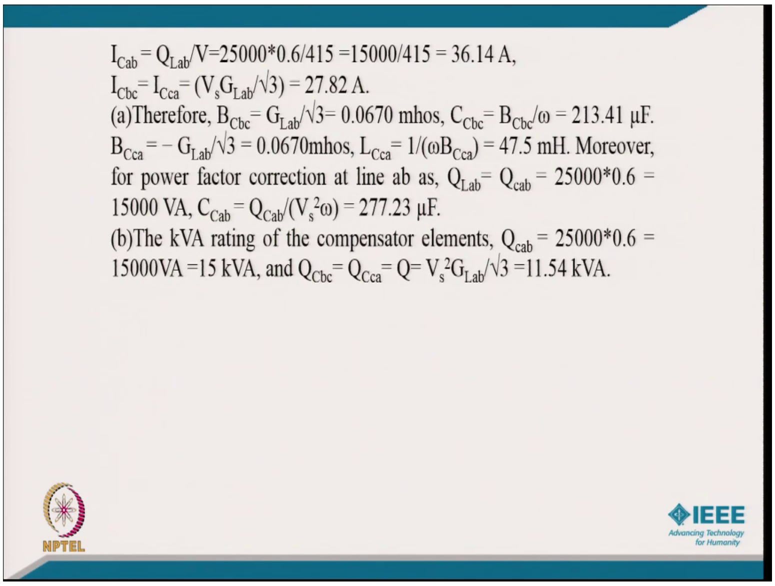

And that is 25000 into typically 0.6, that will be a reactive power divide by 415, [FL] it is a 15000 by 415 and equal to 36.14 Ampere. Similarly, I Cb will be again V s G Lab by root 3, [FL] again this current is 27.82. [FL] therefore, the B Cbc will be G Lab by 3, [FL] that is 0.067 mho and C bCbc by omega, it comes in 20, 201, 213.41 micro Farad and B Cca as G

Lab by root 3, [FL] it comes around 0.067 mho and L Lc will be 1 upon omega B Ca that comes 47.5 milli Henry.

[FL] moreover, for power factor correction at line a b across the line a b such as Q Lab equal to Q cab equal to 25000 into 0.6 that is a reactive power and capacitance equivalent will be because it is a single-phase circuit, [FL] Q Cab V square omega and this comes to 27.23 micro Farad.

[FL] kVA rating of compensator element, you can find out across the a b that was typically of 15 kVA and Q Cb and Q Cb other two will be V square G L upon root, that will be 11.54. [FL] after putting these three compensator, we will get a unity power factor sinusoidal balance current in the net compensated load like.