Power System Analysis
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Lecture - 15
Power System Components and Per-Unit System

So, where we just finished that one that. So, this is understandable that V ac is equal to v angle I mean you just take 180 degree opposite that is V ca and it is V ac.

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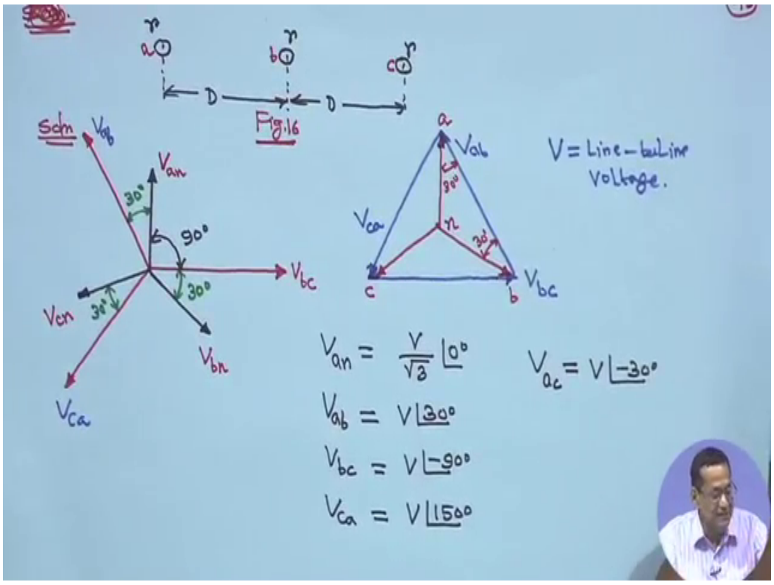

This angle will be 30 degree just now I showed this angle will be 30 degree. And is line to line voltage So, this line will be V ac line to line voltage lagging from V an by minus 30 degree all these things are known and line is untransposed right; that means, that is charged expression of charge will become complex right. So, now, apply equation 5 again you have to go back to equation 5.

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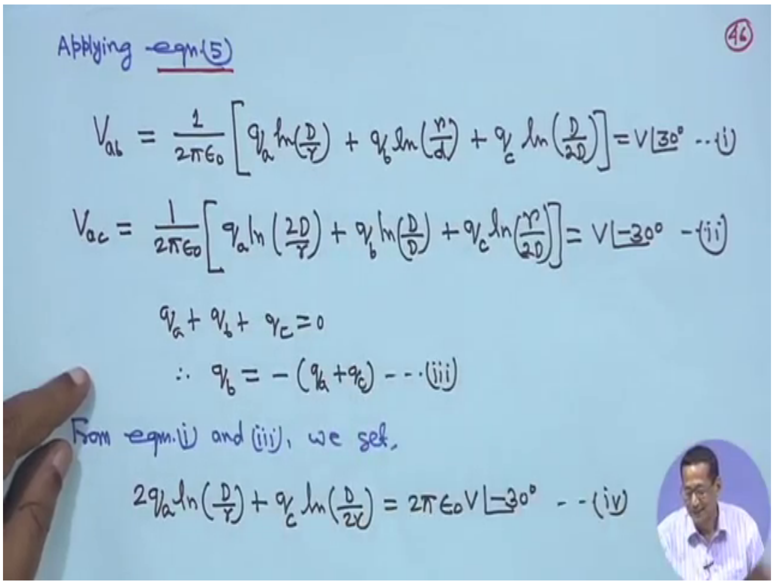

And apply for line voltage say V ab. So, V ab is equal to 1 upon 2 pi epsilon 0, then I am not saying again the equation 5 already has been derived, just you apply that right. Just you see that this thing just you see this configuration and you apply right. So, it will be 1 upon 2 pi epsilon 0. Q a l n D upon r plus q b l n r upon d, plus q c l n D upon 2 d is equal to v angle 30 degree, this is equation 1 right. Because V ab is equal to v angle 30 degree right. Therefore, we are writing that it is equal v angle 30 to this expression is equal to v angle 30 degree this is equation 1.

Similarly, V ac, because we need V ac because V ab plus V ac is equal to 3 V an. So, V ac will be 1 upon 2 pi epsilon 0 q a l n 2 D upon r plus q b l n D upon d; that means, this term will be eliminated right. Because this conductor while you are considering a to what you call V ac a to c right. So, this thing will come that q b l n when you consider this q b this q b this is your conductor b this side is d this side is also d. So, that is why this will come q b l n D upon d; that means, l n one this term will be vanished it is 0, it will be 0 right. So, I will not put anywhere in the expression it is0, but let us take will as this is 0 and accordingly we will evaluate plus q c l n r upon 2 d is equal to v angle minus 30 degree where V ac is equal to v angle minus 30 degree; that means, V ac is equal to v angle minus 30 degree right. Just now we have discussed that. So, this is equation 2, now q a plus q b plus q c is equal to 0 because it is a balance system therefore, q b is equal to minus q a plus q c right. This is equation 3. So, from equation 1 and 3; that means, from equation 1 and equation 3; that means, q b is equal to bracket minus bracket q a plus q c you substitute here, you substitute that q b is equal to minus q a plus q c and simplify. If you do So, you will get 2 q a l n D upon r plus q c l n D upon 2 r is equal to 2 pi epsilon 0 into v angle minus 30 degree. This 2 pi epsilon cross multiplication. So, 2 pi epsilon 0 into v angle minus 30 degree this is equation 4 right.

Similarly, solving the next; that means, this expression is actually in terms of q a and q c. This expression also this equation 2 also is a function of q a and q c, because this term is 0 this term is zero; that means, you solve equation 2 and equation 4 right.

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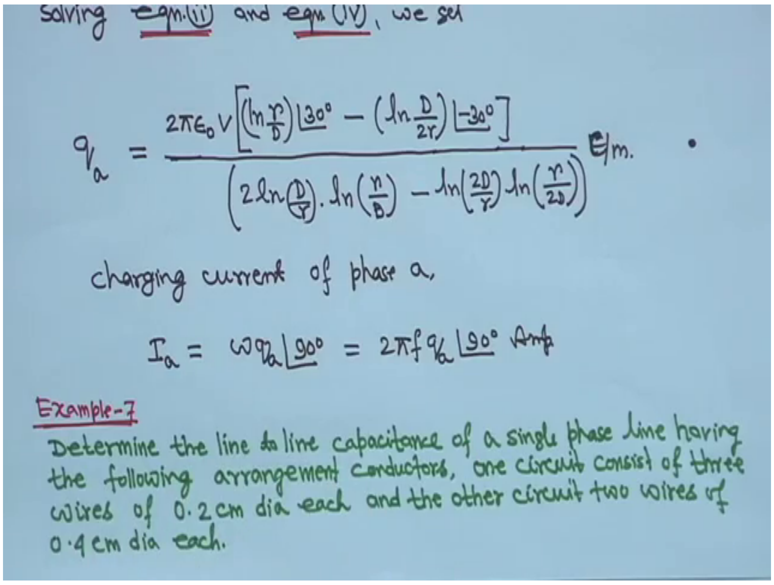

Therefore if you solve equation 2 and equation 4 then our interest is only q a similarly q c also you can solve for q c, but our interest to find out the charge right. This is actually that is coulomb, coulomb per meter right. So, this if you solve for q a it will be it will be your 2 pi epsilon 0 v in bracket l n r upon d angle 30 degree minus l n D upon 2 r angle minus 30 degree divided by 2 into l n D upon r into l n r upon d minus l n 2 D upon r into l n r upon 2 d is coulomb per meter right. So, this; that means, this expression is complex because you have angle 30 degree here angle minus 30 degree here right. Because line is untransposed right. So, charging current of phase a I a is equal to omega into q a angle 90 degree right. So that means, 2 pi a into q a angle minus angle 90 degree. Because current is your charging current of phase a that is why I am putting it is charging current of phase a. So, instead of I a, I can put charging current say I c a right. Charging current of phase a omega into q a angle 90 degree actually q is equal to in general c v right. So that means, your directly you can write omega q a angle 90 degree charging current is leading and this q a expression if you substitute not putting it here that is the expression of the your charging current ampere right. So, if; that means, what that if the if the line is untransposed the charge actually coulomb per meter is a complex quantity right. So, this is your what you call that expression. So, not very difficult one just you have to understand little bit and all these things are we have tried to explain right.

So, next another example. So, this is your determine the line to line capacitance of a single phase line having the following arrangement of conductors. One circuit consists of 3 wires of 0.2 centimeter dia each and other circuit of 2 wires of 0.4 centimeter dia each right. After this example we will stop the capacitance one right. So, this is the last example for capacitance one. So, this is for inductance case inductance case we have solved this in this composite conductor x 3 conductors are here and here m is equal to your what you call 3, and here n is equal to 2, 2 conductors are there right. Therefore, first you find out D eq that is all the mutual distances. So, 3 conductors 2 are here 3 into 2 m n is equal to 6 I have written 2 to the power 1 upon m n. So, D aa dash, D ab dash, D ba dash, D bb dash, D ca dash, D cb dash right. So, all these distances here all the things I have shown you all 4 meter 4 meter is given this is 6 meter is given, this 4 meter is given all other distances you can easily compute I have directly written, but this you can easily make it right.

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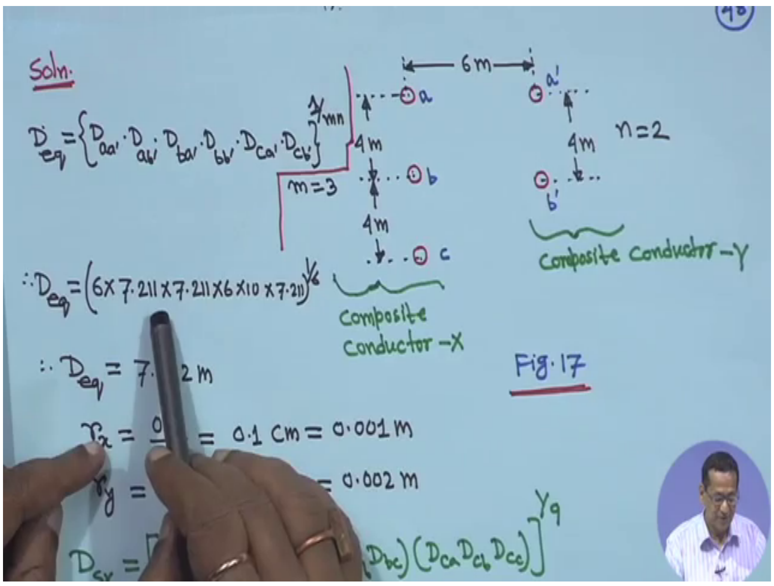

So, it is 6 into 7.11 into 7.11 into 6 into 10 into 7.11 to the power 1 upon 6. It will come 7.162 meter right. Similarly r x the group x right. All the radius your diameter same 0.2, for this one, this one, this one. So, radius will be 0.2 by 2 that is 0.001 meter. Similarly here also this group radius is diameter is 0.4 centimeter. So, r y is equal to 0.4 by 2 is equal to 0.2 centimeter is equal to 0.002 meter right.

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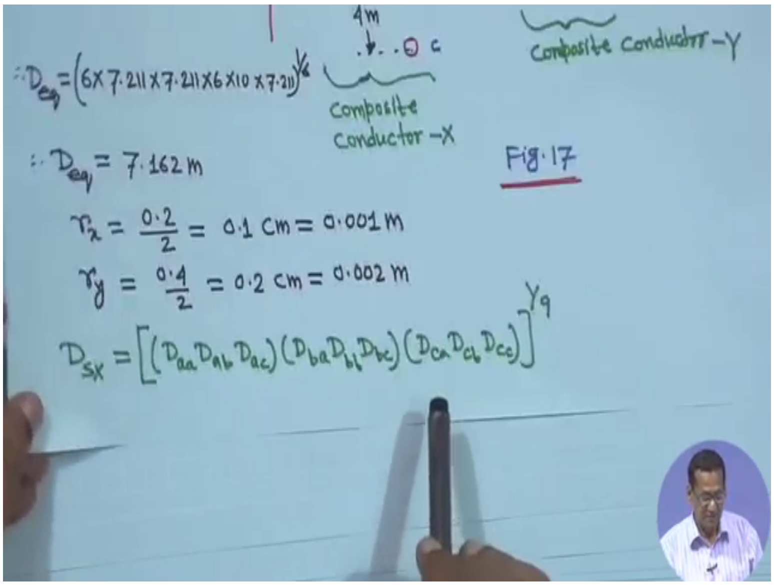

Therefore find out yourself one with the self G md 1 for this group for this group right. Therefore, D sx, D aa, D ab, D ac, D ba, D bb, D bc, D ca, D cb, D cc. D aa, D bb and D cc actually is equal to r x. And all the 9 possibilities 3 into 3. So, to the power 1 upon 9 right.

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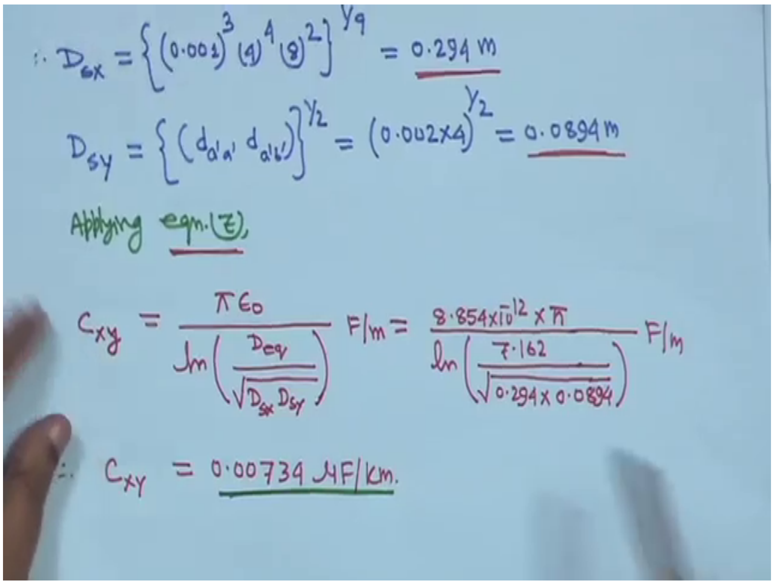

So, you can easily calculate this your D sx. So, it is 0.001 q into 0.4 to the power 4 into e square to the power 1 by 9. So, 0.294 meter right. Similarly D sy is equal to your is equal to your d a dash a dash into d a dash b dash to the power half, whatever it comes 0.0894 meter. So, now, again apply equation 7, whatever has been derived right. And C xy pi epsilon 0 l n D eq upon root over D sx into D sy farad per meter. So, substitute all these values for D eq D sx D sy, you will get C xy is equal to 0.00734 microfarad per kilometer right. So, with this, with this the capacitance calculation of transmission line now it is over, but when we will come to the your characteristic or performance of the transmission line 3 phase transmission line at that time we will see again this charging capacitance right. And it is effect. So, next one. So, this capacitance one is over right.

Next one will be the power system, your power unit system will start right. So, power system component and power unit system.

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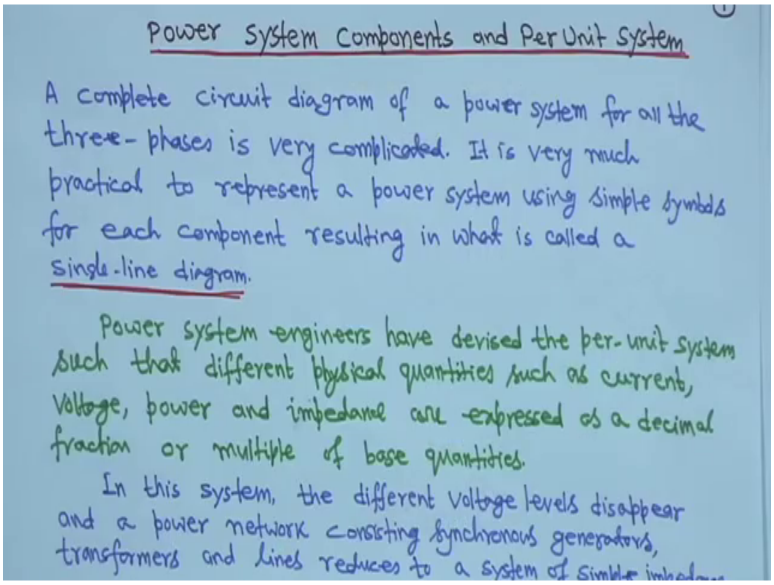

So, here generally you have seen when you are drawing the diagram for power system network right. So, power system component and power unit system that basically, we are making single line diagram right. We are although it is a 3 phase system because 3 phase is your 3 phase system is a balanced system. So, and that is why it can be represented by your single line diagram. And another thing is that, but if system is unbalanced then you have to consider that the mutual coupling between the conductors as well as between the conductor and the your neutral right. I mean I would make it like that that between the phases you have to all the mutual phase conductors as well as phase to neutral conductors, you have to consider the mutual inductance if system is unbalanced, particularly for the transmission line that each phase is carrying almost the same power. It is a balanced system voltage is also balanced, but when you come to distribution system say 11 k v system distribution in our country mostly it is 11 k v system. So, your distribution system in that case that is each your loads are not balanced. Some cases it is unbalanced. And in that case you have to consider the your, what you call, that your mutual inductances in that case those things cannot be represented by a single line diagram right. You have to consider all the 3 phases. So, so power system components So, for transmission system will go for this thing single line diagram, we will come later. So, a complex circuit diagram of a power system that is why I have written something for all the 3 phases it is very complicated. Because you have a b c, 3 phases and different components are there like synchronous generator then transformers right, circuit breakers right. And if many other devices like shunt capacitors reactors or facts devices and then, your what you call then your all other things all the your what you call components, if you put it together it looks very complicated right. So, it is very much practical to represent a power system using simple your symbols. For each component resulting in what is called a single line diagram right. So, that is why the power system engineers has devised a power unit system, such that different physical quantities such as current voltage power and impedance are expressed. As decimal fraction or multiple of base quantities right.

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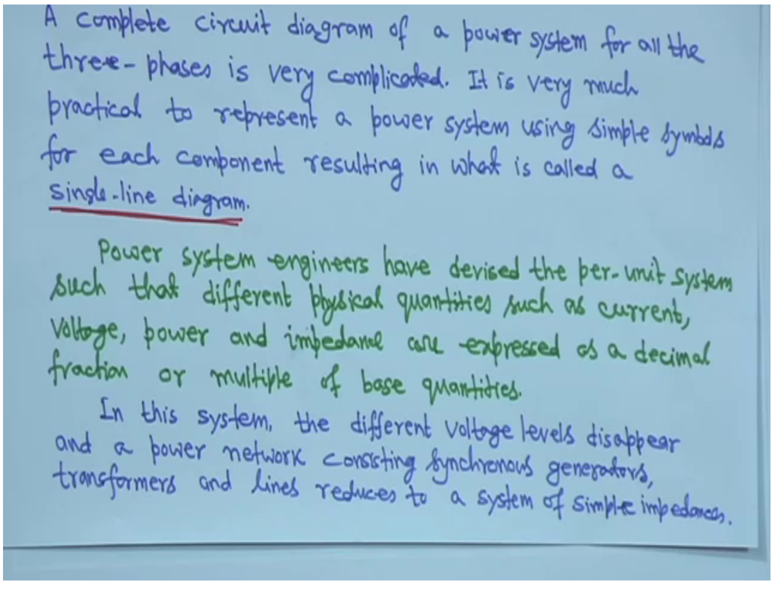

So, in this system the different voltage level disappear, when you go for power unit system you will find it is all the quantity, So you will be given a dimensionless quantities. So, voltage level will disappear and it will power network consisting of synchronous generators transformers and line reduces to simple impedances right. So, this is the major advantage of power unit system right. Once you transform everything in power unit system, then things will be easier, but before that you have to understand actually, how to, how to convert the power unit system? From one base to another. So, sometimes students they make some silly mistakes for power unit system right. So, conversion. So, let us see how we can make it.

First thing let us start like this right. A single phase represent representation of a balanced 3 phase system.

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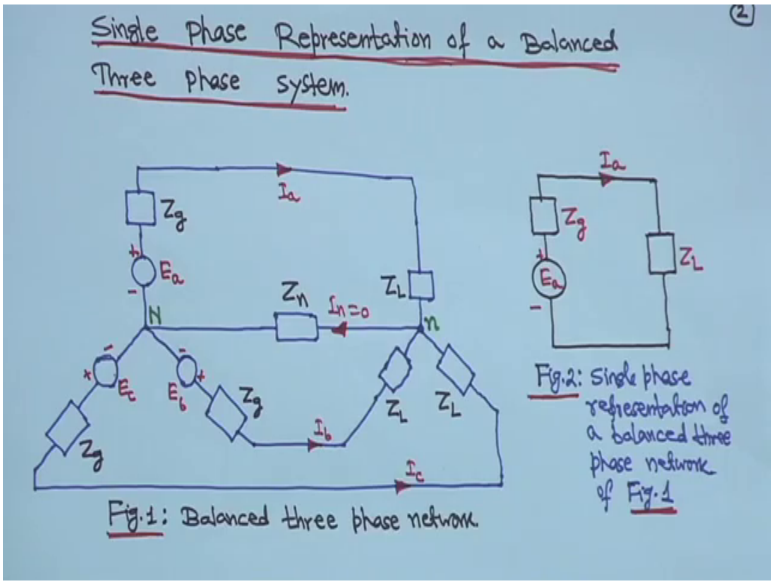

Suppose I mean suppose this one for example, suppose this was a 3 phase supply system right. So, simple thing, So this is say this is your synchronous generator say for example, this is phase a your this is phase b and this is phase c voltages right. And impedance is given Z g stands for impedance of the generator synchronous generator, let us say right. And this is the 3 phase load star connected right. And impedance of the this one Z L, Z L, Z L that is the balanced system. So, it is a neutral to neutral is connected, but as it is a balanced system. So, no current is flowing through the neutral therefore, this neutral impedance here to here Z n will have no effect right. As long as it is the balanced system, but in the reality in reality actually nothing is completely ideal right. So, it cannot completely balance, but it is balanced right; that means, in this case this is a balanced 3 phase in this case rather than as it is a balanced and all the, all the, all the phases all the phases phase a, phase b and phase c carrying equal power; that means, equal current right. So that means, each one instead of considering all the 3 phases we can consider only one phase. So, that is why only phase is drawn because neutral is not carrying any current 0. So, Z n has no effect. So, in that case your E a your voltage of the phase a Z g will be there this one and this is Z L and ultimately your what you call, that expression of your phase a equivalent circuit diagram of phase a right. So that means, that rather than 3 phase we can represent it by your single your single phase circuit. That is E a is equal to if you apply k v l in this equation it will be basically your Z g plus Z L into I a is equal a; that means, a is equal to Z g into I a Z g plus Z L into I a right. So, this is a single phase representation of balanced 3 phase network of figure one right; that means, this from circuit theory also 3 phase circuit analysis also you have studied this kind of diagram right.

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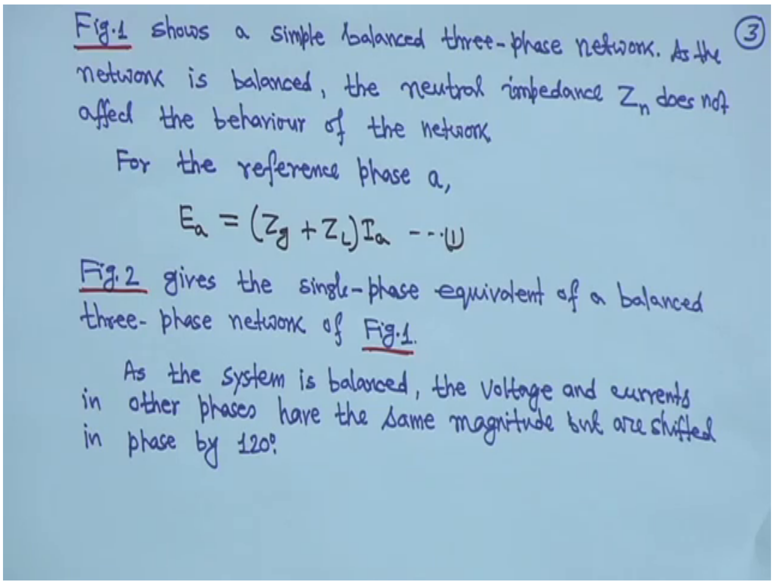

That means that is that is your, figure one I have explained everything. So, figure one your that is; that means, that means this figure this is figure one and this is figure two; that means, figure one shows a simple balanced 3 phase network as the network is balanced the neutral impedance I told you Z n does not affect the behavior of the network. Therefore, from the for the reference phase a that is figure 2 we can write a is equal to Z g plus Z L into I a this is equation 1 right. So, this is a new topic. So, again starting from equation 1 and figure two; that means, this one gives the single phase equivalent.

So, figure 2 is the single phase equivalent of the balanced 3 phase network of figure one, as the system is well balanced, the voltage and the system is balanced; that means, voltage and current in other phases only have the same magnitude, but phase shifting will be 120 degree right. We have as you know if you take one is reference, then another will be 120 minus 120 and minus 140, 240 right. The way you want so, but magnitude will remain same only that phase difference will be different. Now for a transformer we will come now to the transformer. This is very important thing.

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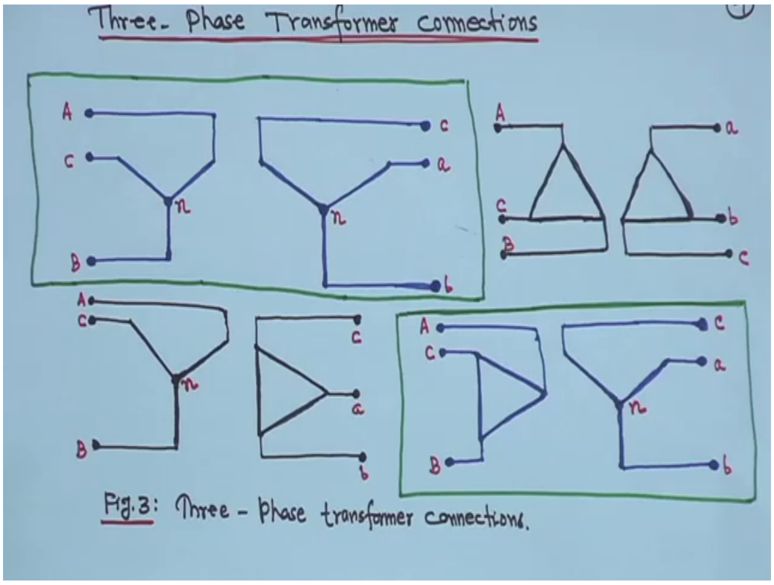

Many things here You have to understand, as far as your thing knowledge is concerned things are very simplified basically, that your 3 phase transformer is 3 phase power is transformed by use of 3 phase unit is right. Particularly for high voltage extra high voltage system, that rating of the transformer is very high right. In that case if you try to design a 3 phase transformer then it occupies actually a huge volume and insulation problem also right. That is why what they do they take 3 phase sorry, the 3 single phase transformer right. And after that they connected in 3 phases. The advantage major advantage is first thing is the insulation clearances second thing is that your transportation, suppose if you design in a single unit as a 3 phase transformer the volume will be heavy, and very difficult to carry it shipping problem or transportation problem. That is why for large power transformer they take 3 single phase transformer and they connect it 3 single phase in 3 phase, such that it should be 3 phase another advantage of such connection is that. Suppose if you take one unit because 3 single phase are there they are making it as 3 phase if one unit is taking you know as a repair, but other 2 phase also you can operate, but rating has, but it has to be derated and rating will be approximately 57.7, that is 1 upon root 3 that is 58.8 percent. Those things for the meshing courses not here, but that is called v connection, but in this case generally transformer you have star or delta right. So, 4 combinations will be there star, star this is star, star right. This convention I have taken from American standard association right, but any thing you can take, but accordingly you have to follow this is star, star connection star, star neutral is available right. For delta, delta neutral is not available right. And star case you know delta, delta case you know line voltage and phase voltage same whereas, star case line voltage is equal to root 3 times the phase voltage and star delta and delta star. So, altogether 4 such combinations are there and all these 4 combinations are your, you have to use mostly use these 2 and other 2 why not will come to that right. So, this is the schematic diagram. Later we putting that each winding that winding now turns and other thing we will come later, but this is star, star, delta, delta, star, delta, delta star these 4 combinations are there right. For the transformer.

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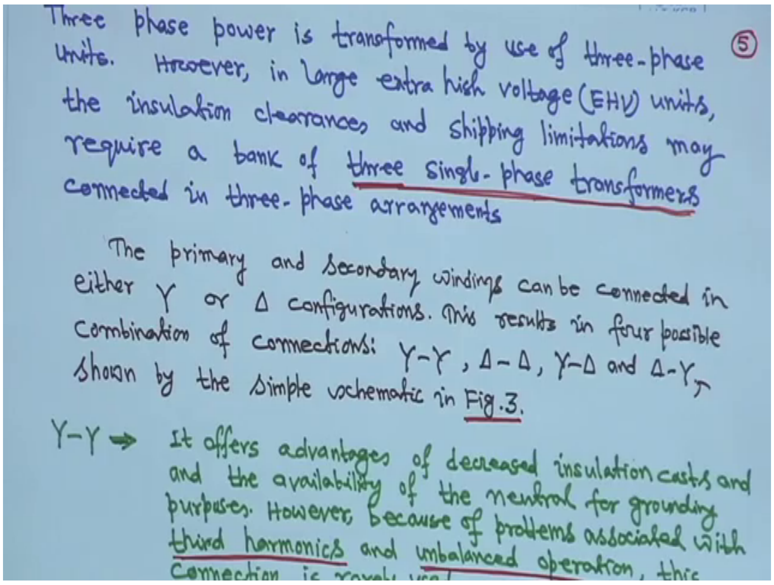

Now, the 3 phase power is transformed by use of I told you, 3 phase unit is; however, the large extra high voltage unit is the insulation clearances and shipping limitations may require a bank of 3 single phase transformer connected in 3 phase arrangement; that means, 3 single phase transformer will be connected in 3 phase, such that transportation is problem. Suppose transportation will be easier suppose manufacturer manufactures these somewhere and you are carrying some thousand kilometers to some other place. So, if transformer is made for 3 phase together a single unit is very difficult to carry because the volume will be huge, but if you make single phase one then connect it then transportation is easier right. So, primary and secondary windings can be connected in either star or delta right. Configuration this result in 4 possible combination of connections that I showed you, the star, star delta, delta star delta and delta star right. As is shown by your figure 3; that means, this one I have shown you all these combinations right.

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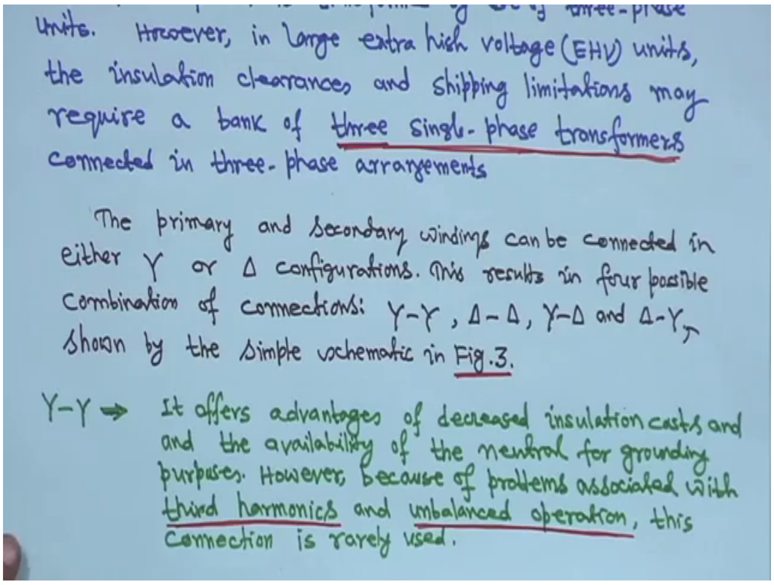

Now star, star it actually offers advantages of decreased insulation. And your insulation cost and availability of the neutral for grounding purposes. For decreased insulation costs means that for star, star that your A to n B to n or C to n that your each winding when you design that only that phase voltage is impressed on the winding not the line to line voltage it is line to neutral voltage. That is why insulation cost will be less right. So, and the grounding facility for the star connection it is there right; however, because of the because of the your problem is associated with the third harmonics and unbalanced operation this connection is rarely used right, but there is no path for third harmonic current circulation for the star, star connection right. And for a unbalanced operation right. So, in that case that is why this star, star connection is rarely used. So, to make this; that means, star, star connection will be there, but not much in use as a your high voltage your transmission system right.

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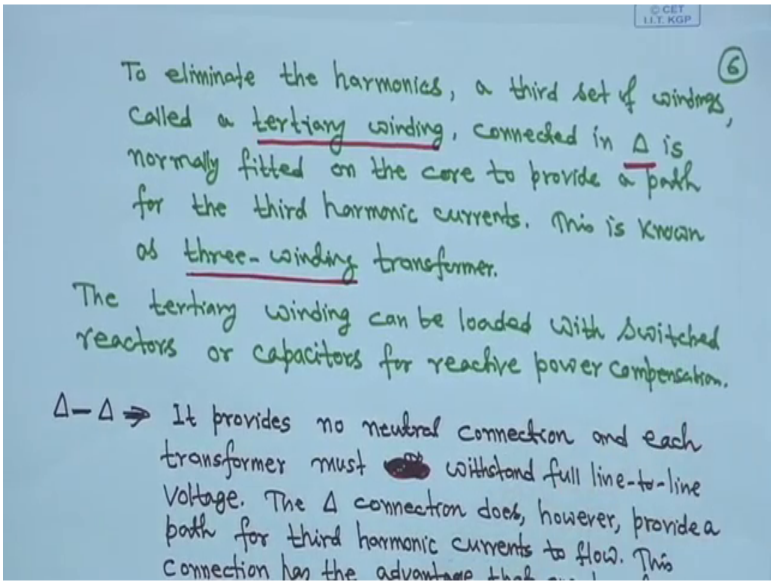

Now, although we will not study, but purpose of your some ideas to eliminate the harmonics a third set of winding called it tertiary winding connected in connected in delta is normally fitted on the core to provide a path of the third harmonic current; that means, third your set of windings called your tertiary windings and that will be delta connected is normally fitted on the core to provide a path for the third harmonic current right. This is known as 3 winding transformers so, but although we will not study here 3 winding transformers, but in laboratory many of you might have done experiments on these 3 winding transformers. So, the tertiary winding it can be loaded with either your switched reactors or capacitors for reactive power compensation right. Although we will not study here, but this tertiary winding is this thing in many cases in your institute or on in your engineering colleges that laboratories these 3 winding transformers are there right. Particularly short circuit to determine the parameters of 3 winding transformers using short circuit and open circuit test right.

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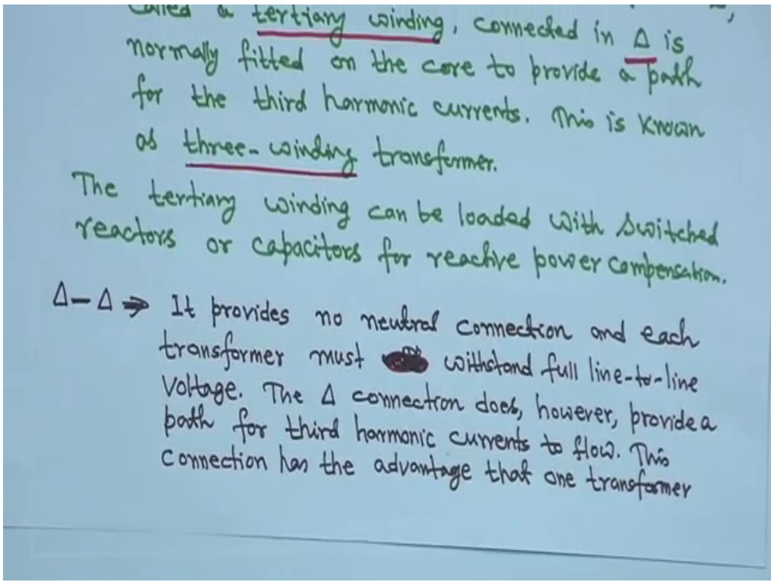

So, now come to delta, delta. Delta, delta actually provides no neutral connection for delta, delta there is no neutral connection and each transformer must withstand full line to line voltage, because for the delta connection for each phase the winding is there it will be full voltage in phase. Because delta line and phase voltage they are same line to line and phase voltage same. So, full voltage will be your to withstand full line to line voltage right. Therefore, the delta connection does; however, provide a path for third harmonic currents to flow delta will because it is a delta connection. So, it provides a path for third harmonic currents to flow this connection has the advantage, that one transformer if you can take it for repair right. Then your other 2 I mean I mean if delta, delta if delta, delta if one winding you because 3 single unit.

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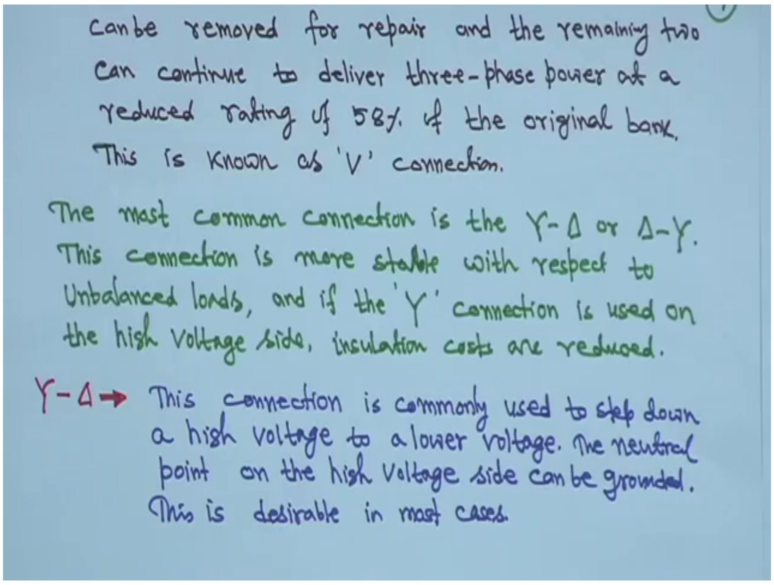

We are connecting it is not a single 3 phase unit 3 single phase unit we are connecting as a 3 phase if one unit is taking out if one is taking out it will be it will call be called v connection right. Or open delta connection right. In that case it still the rating has to be it has to be derated, but still it is 57.7 approximately 58 percent of the original bank it can supply right. 3 phase power at least 58 percent of it is rated value. And this is known as v connection or open delta connection right, but the most common connection is the star delta or delta star right. But this connection is more stable with respect to the unbalanced load and if the y connection is used on the high voltage side insulation cost are reduced. This basically for star delta transformer or delta star transformer the star side basically used for the high voltage basically this side will be high voltage side; that means, when you are using that step down transformer that primary side should be high voltage and this side should be low voltage and we will go for step up then this side should be low voltage this side should be high voltage right.

So, I hope you have understood this right. So, for star delta or delta star are very common because delta star kept under your high voltage side, because each phase that voltage actually will be the phase voltage will be used. So, insulation cost will be less right. So, and for the step down step down transformer suppose 220 by 132 k v right. So, this side actually it should be high voltage side this should be low voltage side. So, if you step up this side suppose for example, 33 to 220 k v for example, say. So, this side will be low voltage side this side should be high voltage side. So, star delta or delta star, star side should always be at the high voltage side and delta should be always low voltage side. I hope this part you have understood right. So, therefore, the star delta connection is commonly used in step down, just now I told a high voltage to a lower voltage. Just now I have told everything the neutral point on the high voltage side can be grounded these are available in most cases. Here it is not shown for star side neutral point will be grounded this side also will be grounded although no diagram I have shown it here, but later we will show right.

So, neutral will be grounded and when we will study the study another thing at that time we will see about all this right. So, neutral side of the star should be grounded here also it should be grounded right. This is desirable in most cases same thing, same thing for delta star I told everything right.

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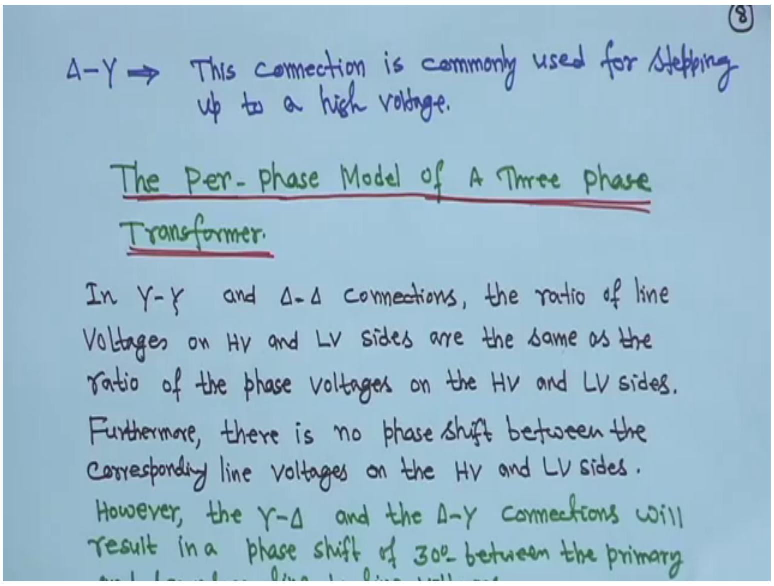

For delta star this connection is commonly used for stepping up stepping up to a high voltage, this is also I have told you right. So that means, star delta or delta star, star side should be always on the high voltage side. If you go for step down transformer with star delta connection if you go for step up transformer for power transmission system then it will be delta star right. So, the per phase model of a 3 phase transformer. Now we have to see for per phase model here you have to understand a lot right. So, in star, star or delta, delta connection the ratio of the voltage on high voltage and low voltage side.

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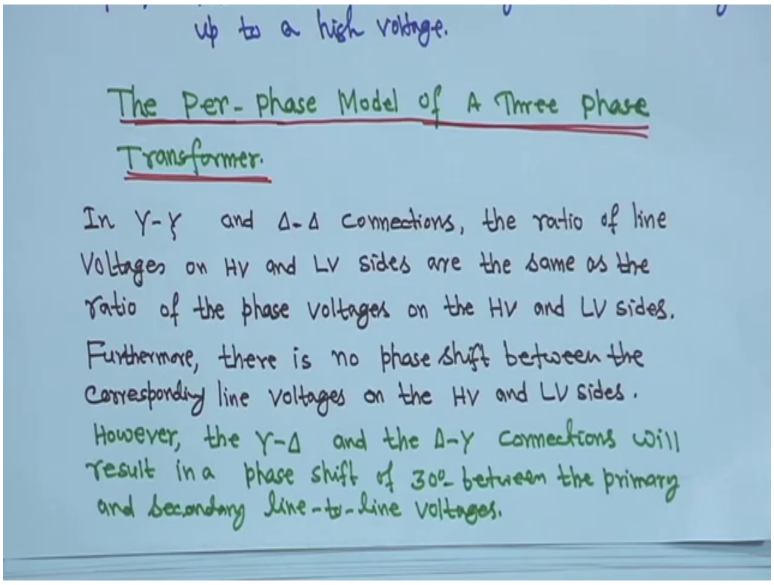

At the same as the ratio of the phase voltage on the high voltage and low voltage side. If you take very simple it is if you take star, star or delta, delta connection you can draw yourself. So, ratio of the line voltage on high voltage and low voltage side are the same right. Because are the same as the ratio of the phase voltage on the high voltage and low voltage side. Because in star, star the ratio of the voltage in the high voltage and low voltage because star, star case that your, what you call that, line voltage is equal to root theta in phase voltage and for the delta, delta case line voltage and phase voltage both are same. So, that is why the ratio of the phase voltage on the h v and l v side they are same. You can do it because you have studied also meshing right. Electrical meshing further more there is no phase shift between the corresponding line voltage on the high voltage and low voltage side. For star, star connection and delta, delta connection there is no phase shift between the corresponding line voltage on the high voltage side and the low voltage side. Look I am not using any primary or secondary I am only talking about the high voltage and low voltage right. So, so no phase shift for star, star or delta, delta right. Between the corresponding line voltage on the high voltage side and low voltage side right; however, star delta and delta star connects and will result in a phase shift of 30 degrees; that means, star delta or delta star their connection will result in a phase shift of 30 degree between the primary and secondary line to line voltage. Now I am coming to between primary and secondary line to line your what you call voltage right. Between the primary and secondary line to line voltage.

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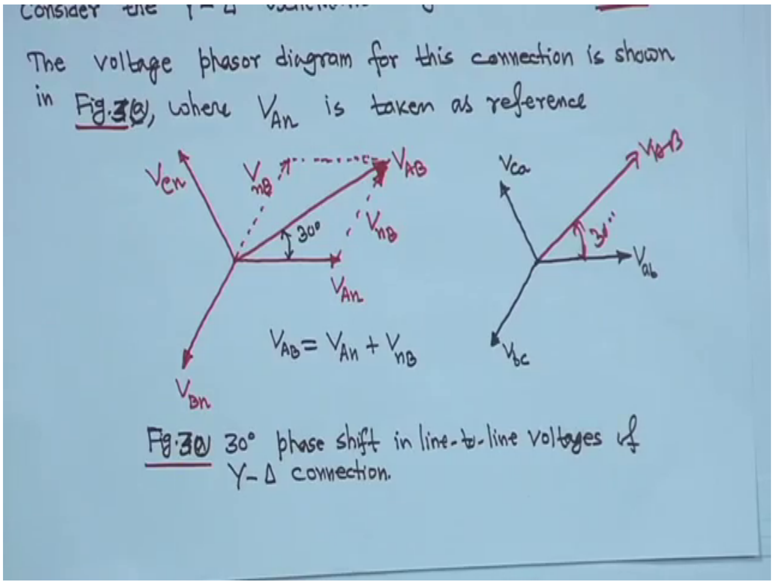

For example this is for example, you take star delta connection, consider the star delta schematic diagram of figure 3; that means, this diagram just now we have seen no this diagram this one star delta right. So, in this case your this side star side actually capital A B C and delta side small a b c delta is line and phase voltage same right. So, delta if you draw the phasor this is delta side, V ab v b c V ca 120 degree apart not shown, but you know that is from balance 120 degree. And for the star side right for the star side that V an is taken as a reference. So, this is my V an then V bn and this V cn all are 120 degree apart. So, this is V bn. So, take V bn just hundred 180 degree. So, just opposite. So, this is V nb; that means, this is my V bn right; that means, v this means this is then you make this complete this is V ab. So, V ab is V ab is equal to V an plus V bn right. So, this is my V ab So that means, this angle is 30 degree; that means, this is V an, but this V ab is 30 degree now if you put if you if I if I make this one if I make this one here if I make this V ab here suppose this is my V ab then this angle is 30 degree; that means, that means, this star side line voltage, star side line voltage leading the delta side line voltage by angle 30 degree this is delta side line to line voltage and this is star side line to line voltage V ab. So, v capital A capital B right. So, V ab is leading V ab by 30 degrees; that means, for star delta or delta star there will be phase shift of 30 degree, got it no?

Thank you.