Electrical Machines - I
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Lecture – 43
Choosing Transformer Connection

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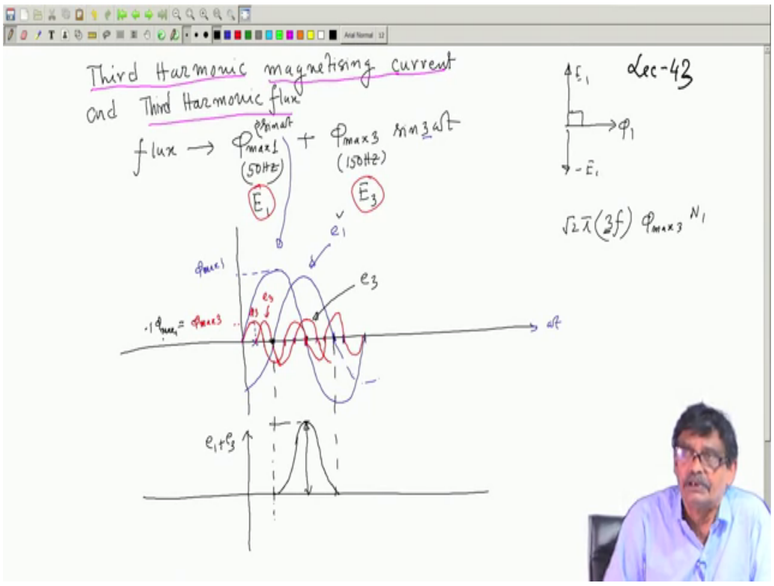

Welcome to lecture number 43 and we have been discussing about Transformer Connections and then we told you that in transformers because the b h curve is in fact, a loop although very thin loop, but nonetheless it is not a straight line relationship between b and h. So, what happens is this in our last class the conclusion was qualitative discussions on that.

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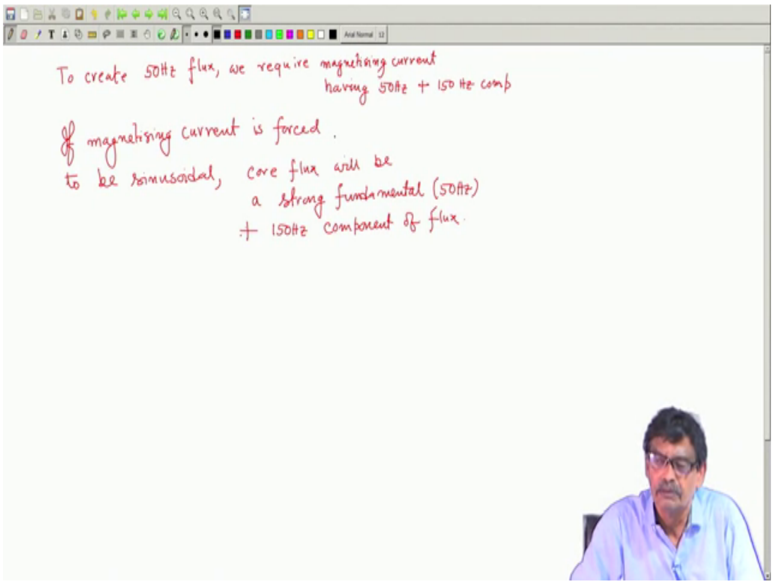

Remember that these are the two things that is, if magnetizing current happens to be sinusoidal 50 Hertz then core flux will have both 50 Hertz and 150 Hertz component ok. On the other hand if the flux in the core is 50 Hertz only then magnetizing current must have 50 Hertz component as well as 150 Hertz component, then depending on situations the current may not have a 150 Hertz component.

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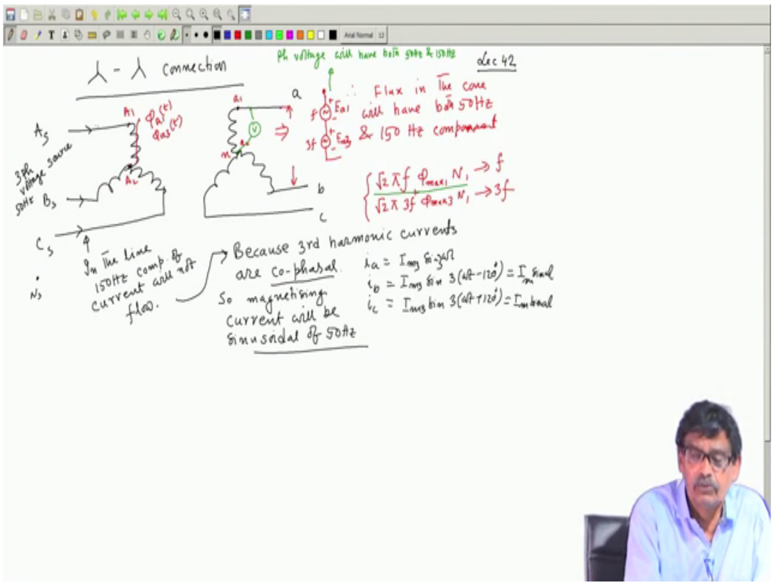

In case of say star star connections without neutral connected anywhere no scope for any third harmonic current to exist in the lines of this transformers and therefore, the flux must be having a 50 Hertz as well as 150 Hertz component; other higher order harmonic components are also there, but we are neglecting that because their amplitudes will become smaller.

But your voltage phase voltages then will be distorted, although there will be no effect of the line to line voltage that will only have 50 Hertz components ok, but phase voltage will have that 150 Hertz component.

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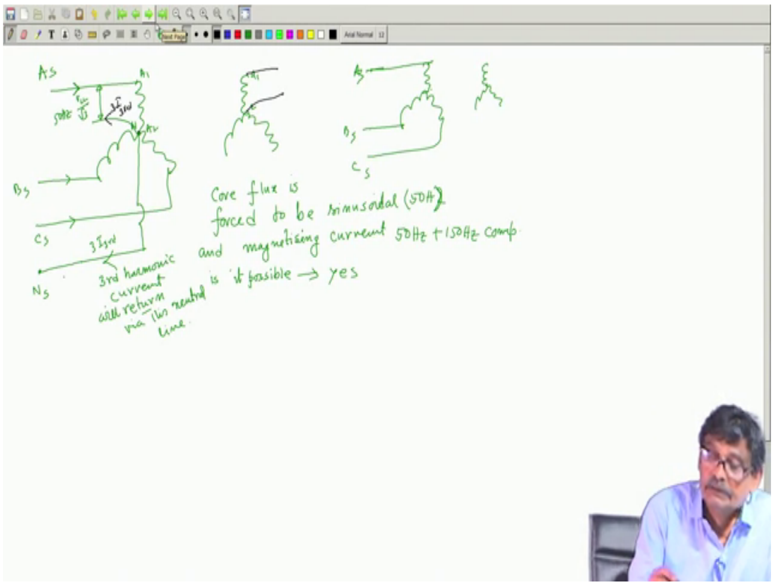

Anyway this sort of thing happens and we must have we must give importance to these because of this fact. Now, although I have not drawn any voltage or current waveform showing the fundamental flux and the third harmonic flux and the associated induced voltages.

Today I will just draw those waveforms, so that we will understand what happens if the flux is distorted. Suppose flux in the core has both phi max 1 50 Hertz component plus phi max 3 that is the 150 Hertz component this is sin omega t and this is sin 3 omega t; sin omega t this into sin omega t and this 3 omega t.

Then both of them are going to induce voltage. So, in essence what I have assumed is these the exciting or magnetizing current is 50 Hertz component that is why flux has come out to be this and then I want to see that E 1 and E 3 third harmonic component and the fundamental how they will look like.

Remember each one of them will induced voltage d phi d t if you do and the angle with which that induced voltage will appear is 90 degree that is known because you remember we draw like this is the flux wave phi 1 then I draw E 1 like this 90 degree relationship or in books some of the books they will write minus E 1, but nonetheless the angle is 90 degree between them.

So, let us try to sketch that flux and induced voltage waveform to understand whether this is really detrimental because phase voltage as in case of star star connection we will have both fundamental and third harmonic component, what happens to the with respect to time how the resultant voltage looks like that is the goal.

So, what I do is this suppose I say that I will try to sketch the waveform. Suppose I say that this is suppose it is necessary I divide these are suppose fundamental 60 degree 180, then another 180 ok. So, let us see suppose the fundamental flux I am sketching; so this is half period ok. So, it will be suppose like this; this is the fundamental component one to three and it will be like this. So, this is this phi max sin omega t I draw it.

Similarly, on the same graph I will draw phi and this amplitude is phi max 1; phi max 1. Then I sketch the third harmonic component in the time axis. Now, since it is 3 omega t when it completes one cycle the third harmonic component will have 3 cycles over the period fundamental period. So, it will be then how, it will look like it will be like this; this; this. So, it will be the third harmonic component if I sketch it will be like this to 3 cycles over 360 degree fundamental and this amplitude is phi max 3.

Then the induced voltages that is E 1 and E 3 I will sketch with respect to time that will be displaced by 90 degree, it does not matter whether you show leading or lagging to understand what is going to happen. So, I will just sketch the induced voltage which will be; so this angles are 60 degree in the fundamental understand. So, the induced voltage because of the fundamental I will sketch it say 90 degree lagging I am sketching it does not matter. So, it will start 0 here this is 90 degree 60 plus 30 90 degree and where it will end it will be here half cycle.

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60 180 degree this one.

Student: That one (Refer Slide Time: 09:07).

Student: (Refer Slide Time: 09:09).

Here it will be, this is becoming 180 degree.

Here. So, the induced voltage corresponding to fundamental it is also I am drawing blue. So, it will end over here, but I have shifted by 90, so it will be here.

Student: Let us imagine.

Here.

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So, this and this. So, induced voltage is suppose like this because of fundamental and it continues. So, this is the fundamental induced voltage E 1 and because of phi max three that voltage also will lag this red coloured curve by 90 degree with respect to its angle. So, this is no degree here, is not. So, it will start from here and where will be the first cycle, it will be that is it will be where?

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This up.

Student: (Refer Slide Time: 10:30).

This will be the first.

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That is this will be one half of this cycle are you getting. So, it will start from here, it will go there, it will come and then it will go there and here.

Student: (Refer Slide Time: 11:02).

Here, this will be the induced voltage and let us draw this is E 3 mind you E 3 and then I draw the next cycle it will be like this it will come here.

Student: Ok.

Like that. So, phi 3 this is phi 3 first one 90 degree lagging with respect to this phi 3 if this is E 3 like that it will continue. Now, if you see the resultant voltage below this I will sketch that is here I will sketch E 1 plus E 3 that is this one and this voltage, you see the peak voltage this voltage waveform will be p k in nature. So, it will be in one half cycle that is in this timeframe if I sketch other half will be similar. So, you see it will be like this here this peak and this peak coincides. So, it will be somewhat decaying next half it will continue. So, the peak of this instantaneous voltage across the coil will become this much.

Now, the question is what is the order of the third harmonic flux? It may be of the order of 8 10 percentile ok. Suppose then if this is phi max 1, phi max 3 will be about 0.1 phi max 1 suppose let us do that, then this induced voltage third harmonic may be as high as 30 percent. Why? Because number of turns is more remember the RMS voltage is root 2 pi f for third harmonic its 3 f root 2 pi f phi max 3 into same N 1 therefore, that induced voltage will be then about thirty percent or so. So, the induced voltage this E 3 amplitude will be about 30 percent E 3 amplitude will be about 30 percent of the fundamental voltage therefore, the peak voltage will be this much.

Therefore, if third harmonic flux is present your transformer insulation there will be stress upon the insulation of the transformer. Suppose we have not thought about third harmonic flux and we design the transformer for the normal wave 220 volt fundamental 220 volt comes induced voltage is also 220 volt based on that suppose we have designed the insulation level.

But now I find that every 20 millisecond there will be 2 peaks and whose voltage will be 1.3 times the rated voltage, so insulation will be stressed. So, that is why people try to avoid this third harmonic flux to be created, not only that there will be on the secondary side there will be also not 50 Hertz you will get if the flux contains third harmonic component, but at the same time the insulation level will be under stress.

That is why you try to reduce them as far as possible or if it is not ten percent it is less perhaps you can carry on with that there will be a little bit of third harmonic voltage like that. So, assuming the third harmonic flux to be 10 percent this will be the picture. So, this is the thing ok.

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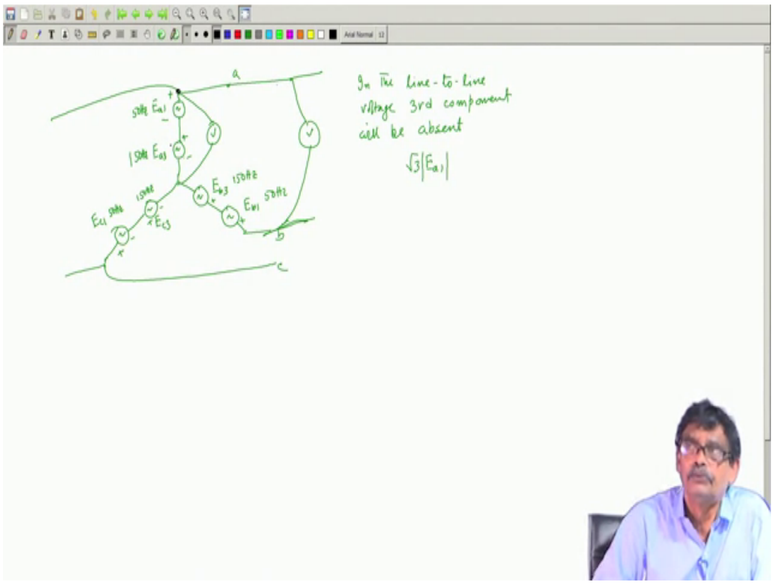

Now, what I will tell we have discussed star star connection, then in star star without neutral connection that we did last time. This was the situation across phases voltages comes, across lines no 150 Hertz component because third harmonic flux voltages will be cancelling out in the lines because they are co phrasal. Then to avoid this and therefore, this terminal this voltage what I was telling is instantaneous value may be 30 percent higher than the fundamental component of this voltage that is how this stressing upon the insulation comes in, we cannot allow this to happen in general.

So, to avoid this I told you one method you connect this to supply neutral. The moment you do this the flux in the core cannot, but be sinusoidal 50 Hertz and therefore, current must have a third harmonic component. Can third harmonic component of current exist? Yes, it can because the return path is through this neutral wire. Mind you the third harmonic current will be contributed by all the other phrases they are co phrasal I third will flow through the line.

And the disadvantage of this method is that it is it may interfere with nearby communication circuit it is not a good solution, but nonetheless it will force the phase voltage to be 50 Hertz as well as line to line voltage 50 Hertz that is what we desire so far as load is concerned is there any better method of avoiding this. We will come back to this connections star star after some time once again to tell you another interesting observation or right now should I tell let us see. So, this point you have understood.

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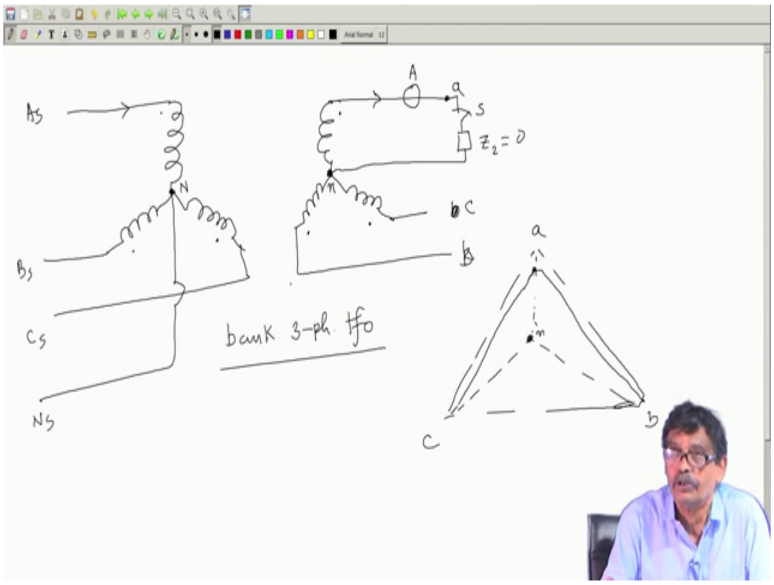

Another disadvantage of star star connection let me continue with that. Suppose we have a star star transformer primary and secondary is also star star and this of course, is and neutrals are not connected anywhere they are living their own life it is not a member of N s supply neutral. So, this is your A s suppose B s, C s and here is your low terminal a b c say or better you call this b this c.

Now, this neutrals are isolated totally; one thing is if you apply a balance free phase voltage line to line voltage is balanced, then I told you in this case across the phases there will be third harmonic component of voltage and now we learned about some idea if third harmonic flux is 10 percent these voltage instantaneous voltage of this may be 30 percent higher than the rated voltage we were thinking of, so put pressure of insulation.

Apart from that suppose we allow that to happen, but another thing is and if you load it will supply load line to line voltage is sinusoidal no problem, but another interesting thing happens here. Suppose I want to put a single phase load on the secondary of a transformer only qualitatively I will tell you.

This is suppose transformer neutral here this is the neutral on this side, suppose I plan to connect a load like this that is I want to attempt to supply a single phase load out of this transformer. And these are suppose dots here b c are open this is quite interesting and suppose I have connected an ammeter in series here to understand what is happening. If you close this with some z 2 connected close the switch the question is how much will be the current in this phase.

It will be tempting that open circuit voltage whatever we had that divided by z 2 will come as the current. So, suppose some current flows here suppose, but this current will. So, far as this transformer is concerned we will have a reflected current here and this reflected current has to flow through the other windings whose secondary is not carrying any current therefore, balance will be disturbed. Is not?

So, what is going to happen? I am telling you will find even if you close it ammeter reading will be very small or no current, that is you cannot connect a single phase load. But then the question is what happens to Ohm's law? This v by z is the current z 2 there was voltage when I when the switch was opened we have connected a z 2.

So, v by z 2 should be the current where then that v by z is equal to I goes that relationship, it goes like this; this secondary voltages this neutral point voltage. It can only happen if I say that after closing you find this current is very little or no current, then I must tell that if very little current then the voltage v a must have been very small otherwise how that is how Ohm's law is also satisfied.

In other words what happens is this the moment you try to put a single phase load this neutral will oscillate, situation will be like this. If suppose I say I will put a direct short circuit z 2 is equal to 0, then also I am telling it is 0. What does all this mean? If you imagine the impedance is so small 0 then the potential of a n and c are same I mean potential of a n and a are same.

If it is 0 this point and this point that is secondary voltage, I am telling this is neutral this is a these are the line voltages etcetera this n point suppose this is the point a this is point b, c this n has come here. So, that the voltage applied across the secondary is the line to line mind you here is a balance 3 phase voltage you have applied this voltage comes here all the time this voltage comes here between b and c line to line voltage exist.

So, when you try to load the secondary of a transformer by a single phase loading this neutral point has come over here indicating that the voltage applied to the other transformer is b n which is almost line to line voltage b a because this is short head. So, this neutral point will oscillate somewhere depending upon the value of z 0 you have connected and single phasing loading you do not do do not ever try to attempt to load a y y connected transformer with single phasing load because of the fact, then the voltage across the other two coils where we have not connected load will approach to line to line voltage.

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Shift sift means with z 2 it will get to somewhere else.

Student: But always useful.

So, in extreme case I told you z 2 equal to 0 n will come here that is this is not a stable point of this neutral this must be understood and this problem will be much more great if 3 single phase transformers with different cores are used. They will not allow a single phase loading because other cores are other cores all the cores are magnetically independent ok.

So, this is another observation this is bank of 3 phase transformer. Anyway you think about it, but single phase loading is not possible, but what happens if you connect the neutral to the source neutral next step, then try to load this fine absolutely no problem. Load this it will invite current and that current will flow here b c is not carrying any current they are mm f s in this line also will be 0 and everything is fine.

Therefore, without neutral connection single phase loading will not be possible with star star connection because then the secondary coils will be very much stressed. In fact, phase voltages it will come out to be across the secondary coils which phases are not carrying any current shifting n to a in the worst case of loading that is you short circuit this. Anyway so, this is just for your information you must remember that. Now, one way of avoiding this third harmonic current in case of star star transformer we have discussed. Therefore, it will be always you will be feeling that, then should I avoid star star connection.

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Now, there comes the other connections for example, star delta connection or delta star connection one of the coils are suppose delta suppose star delta connection I will just draw like this now correct star connection you have made and correct delta connection you have made.

Here will be your load terminals and here is your supply terminals see this is A s, B s, C s. Once again the neutral I have not connected to the source neutral, there is another neutral available suppose 3 phase 4 wire system, but I have not connected. Will there be any problem in this case? Here also I find since neutral is not connected to N s can there exist a third harmonic exciting current? No, in the lines third harmonic current cannot exist. So, what will be the conclusion? The exciting current whatever will be magnetizing current that will be of 50 Hertz component only and pure sinusoidal.

So, if exciting current is sinusoidal I am sure the core flux will have a fundamental and third harmonic component and that is going to induced voltage both in the primary coils as well as in the secondary coils and those third harmonic voltages are co phrasal. So, in this line also there is no scope for any third harmonic current to exist on the load side because there is no return path, but what thing happens is it is a delta winding there will be induced voltage third harmonic component only I am telling fundamental is there they will sum up to 0 and there will be no circulating current. But so far as the third harmonic induced voltage is concerned in this three coils they are co phrasal, is not.

And they find a closed path. So, in this delta inside this in this closed path you find there will be 3 EMF E 3rd, then E 3rd; E 3rd. Along with E fundamental it will be more scientific you also sketch E fundamental this is the situation E 1. Here I will clean it better draw a nice diagram. So, E 3rd E 1, then once again E 3rd, E 1 is there and E 3rd E 1 is there and they are closed is not and these are the output terminals.

Now, in this closed loop you see, so far as fundamental component is concerned this voltages are 120 degree apart they will sum up to 0 and no circulating current will be able to exist here because they are 120 degree apart, but what happens to E 3rd third component of voltage they are co phrasal. So, when this is minus this is plus and have some instantaneous value similarly this fellow same voltage same polarity and they are connected in series.

So, there will circulate a third harmonic current and this current will not be reflected in the lines because in the lines there is no path for return that is E 3rd will come here and find a path here no that is not possible. So, even if you connect a load there will be fundamental component can only exist 3 lines only cannot have any third harmonic current. But now if you look at the operation of the transformer I will say that fundamental component of the magnetizing current will come from A s, B s, C s and the third harmonic exciting current which is needed the transformer will self correct it by circulating a current third harmonic current here.

It is not important that you pass the fundamental and third harmonic component of current through the same primary winding it does not matter because the coils are wound on the core and net MMF decides what is the flux. So, what all you have to see is this although here neutral is not connected I will say fundamental 50 Hertz component of current is drawn from this side and third harmonic component of magnetizing current can circulate here therefore, flux will be reasonably sinusoid.

And your line to line voltage here available which will go to load will be more or less sinusoidal that is how qualitatively it can be explained to. Therefore, it looks like that whenever you connect a transformer you want to decide whether star delta delta star in delta delta also there is no problem because there third harmonic current can circulate see if the connection is delta delta this is delta this is delta. You please think about it qualitatively I am not doing any analysis it can be done, but you will never forget.

Here also if you apply balance 3 phase voltage here, can third harmonic current exist? No, nothing it cannot exist only fundamental component of current will be drawn. If that is there then I will say flux will not be will have a third harmonic component, but if flux has a third harmonic component it will third harmonic voltage induced here as well as there and both will circulate the needed third harmonic current which will not be reflected in the lines.

Therefore, delta winding having a delta winding on a transformer connection becomes perhaps a very good option that is transformer connection one winding is delta at least you can get relieve of this third harmonic problems you do not have to think too much. So, we will continue with this in the next class.

Thank you.