High Power Multilevel Converters - Analysis, Design and Operational Issues
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Lecture - 36
Maltipulse Transformer- Part II

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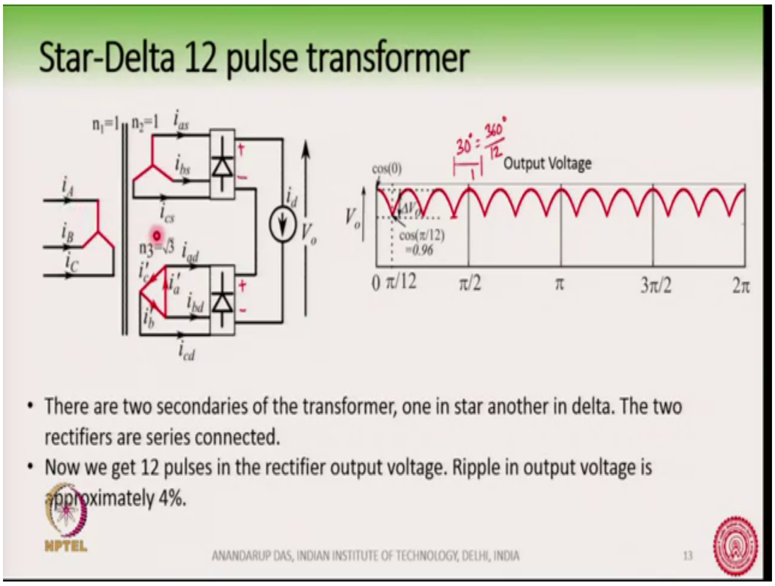

Now, what is there in a 12 pulse transformer. So, the circuit arrangement of a 12 pulse transformer is shown here, you have one secondary if one primary and two secondaries is here. One secondary in star and another secondary in delta connection ok. So, the primary and secondary the star-star connection has turns ratio 1 is to 1 and this star and delta has a turns ratio of 1 is to root 3 ok. Now, in case of a 12 pulse transformer in this fundamental cycle 0 to 2 pi here.

Now, we get 12 pulses in this fundamental cycle or 12 number of lobes here as you can see there are 12 lobes here, in a 6 pulse transformer we had 6 lobes and now in a 12 pulse transformer we have 12 lobes. And why these 12 lobes are happening, because there are 2 diode bridge rectifiers now they are series connected ok. So, the this is the plus. So, you can so, that this is the plus and minus and this is the plus and minus and they are series connected the diode bridge rectifier outputs. So, now, we have a 12 pulse waveform at the output.

Now, when we have a 12 pulse rectifier then of course, the output DC ripple is improved because, you see here that we have now 12 pulses. So, we have this over the width of one lobe is 30 degree, this is 360 degree divided by 12. So, if it is 30 degree, 30 degree then if this is 1 then this value will be cos of 15 degree or cos pi by 12. So, this is what is written here cos pi by 12 this is 1, this is cos pi by 12 and this is 0.96. So, the output ripple, ripple in the output voltage is now only about 4 percent earlier we had seen that the ripple in the output voltage was about 14 percent.

So, the 12 pulse rectifiers were used in earlier days or even now today also 12 pulse rectifiers are used because it gives a substantial improvement on the output voltage ripple ok. But, there is one more benefit that is what we will focus now is the improvement in the input current ok. So, we would like to see how a 12 pulse rectifier or a 12 pulse rectifier from a 12 pulse transformer; how does it improve the input current harmonics ok.

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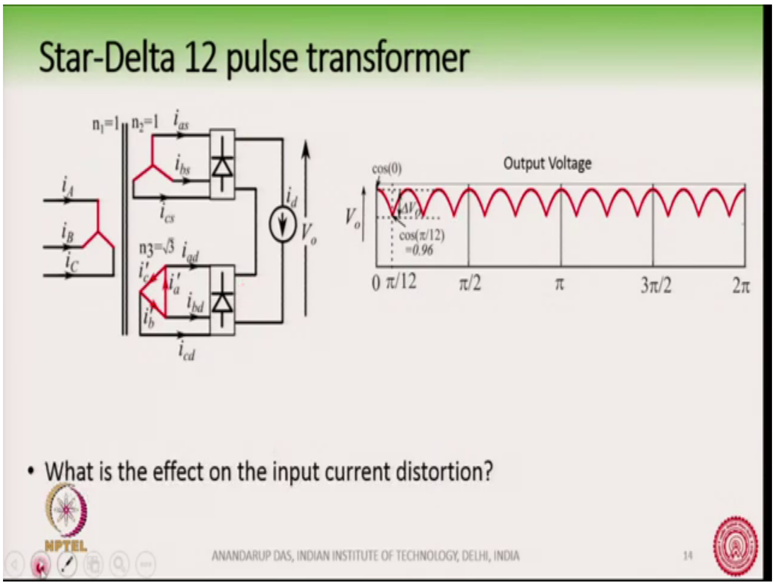

So, that is what we are saying what is the effect on the input current distortion, we are not focusing on the output voltage here.

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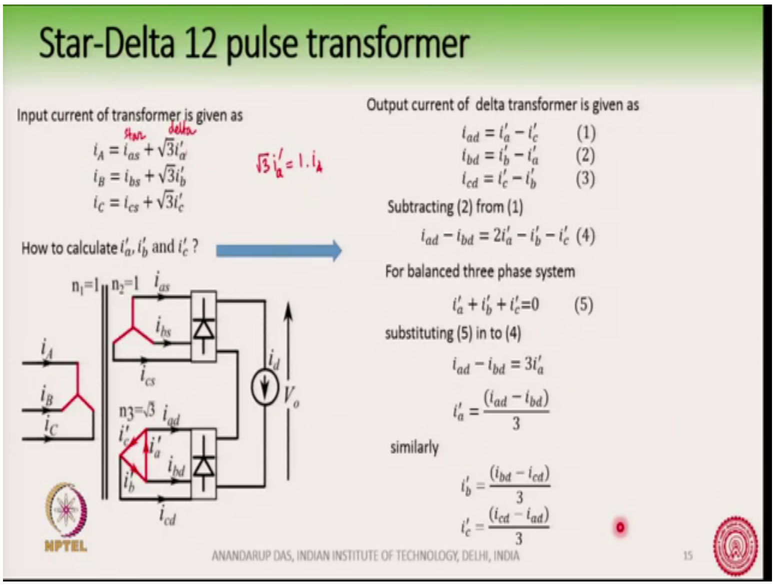

So, in order to understand what is the input current. So, we see we can make the mmf balance on the transformer. So, we have this, this one this has a 1 is to 1 turns ratio and this transformer has 1 is to root 3 turns ratio ok. So, therefore, i capital A here is the sum of contribution from these two transformers ok. So, therefore, i capital A is i as plus root 3 times i a dash ok. So, this has a turns ratio of this one. So, we can also write here. So, this is coming from the star this is this one is coming from the star that is this contribution.

So, i capital A is this i as and this contribution is coming from the delta this is coming from the delta transformer. So, we can say that root 3 into i i a dash is equal to 1 into i a from the for the delta part only we can write this relationship from which we have written this one here root 3 i a dash because the turns ratio here is root 3. So, root 3 times this current is this one similarly, we can also write i B and i C which is following the same procedure ok. Now, then the question comes up what are the values of i a dash, i b dash and i c dash.

Now, the output current of the delta transformer i ad. So, we can write the kcl at this junction. So, i ad is nothing, but i a dash minus i c dash that is what i have written here. In a similar way we can write i bd and i cd as i bd as i b dash minus i a dash that is writing the kcl at these 3 nodes. So, these are the 3 equations here.

So, subtracting 2 from 1 I can find out i ad minus i abd is like this and for a balanced system; if we assume that i a dash plus i b dash plus i c dash is equal to 0. Then we can substitute it back and thereafter we get an expression of i a dash is equal to i ad minus i bd divided by 3 ok. So, we are getting the current i a dash in terms of these line currents, the phase currents in the delta are obtained as a function of these 2 line currents.

So, i a dash is equal to i ad minus i bd divided by three ok. And by symmetry we can also write i b dash is i bd minus i cd by 3 and i c dash i cd minus i ad divided by 3.

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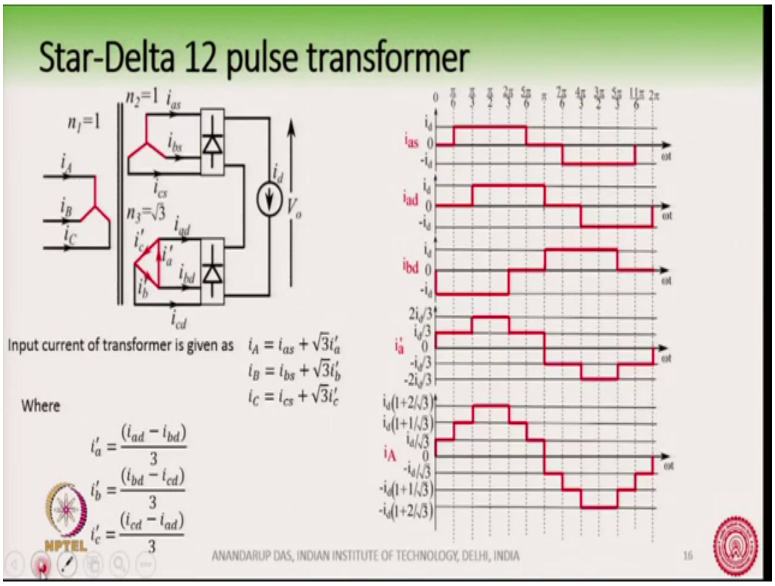

Now, let us look into what are i as and i ad waveforms this is important to understand the waveform of i capital A we are trying to get the waveform of i capital A. We have found one relationship this is this one i capital A is the contribution of the star and the delta that is first and then we have also found out i a dash is a function of these i ad i bd i cd. Now, we would like to plot what is the waveform of i ad and i as this current and this current how will it look like. So, we have seen.

So, this is what we have already studied we have said and also from your basic power electronics you can recollect that the current i as here is a quasi square wave ok; which we have just also said in the few slides back is a quasi square wave like this here that is i as right. Now, i ad is also a quasi square wave this is also feeding a diode bridge 6 pulse rectifier, rectifier here this is a 6 pulse this is another 6 pulse.

i ad is also like this, but i ad is phase shifted by 30 degree why because the line voltage of the delta is same as the phase voltage there is no phase shift. Whereas, the line voltage in a star connection is 30 degree leading to the phase voltage ok.

So, for that reason the sequence of conduction of the diodes in this rectifier will be 30 degree phase shifted and hence the current waveform i ad will be exactly similar to i as, but it will be 30 degree phase shifted. Because of how the diodes are conducting in the upper rectifier and the lower rectifier because, this voltage and this voltage has a 30 degree phase shift between them. So, therefore, i as and i ad will have a 30 degree phase shift in it.

So, if i ad is obtained i can also draw i bd because i bd is 120 degree lagging to i ad. So, therefore, I can. So, this is my i ad and. So, i bd is 120 degree. So, you can see here this is 120 degree or 2 pi by 3 shifted; i bd is 2 pi by 3 shifted on this side. So, once we get i ad and i bd we have seen i a dash can be readily obtained as i ad minus i bd by 3.

So, i ad minus i bd by 3. So, we get i a dash here which is something like this here ok. So, this is the phase current in the delta ok. So, this is the i a dash here. This is the phase current in the delta. So, we have i as here and we have i a dash here. So, these two waveforms we have now obtained ok. Now, we would like to know what is i capital A for which we use this relationship here i as and ia dash. So, both of them we have obtained.

Now, we have to multiply i a dash by root 3 and add it with i as right. So, if we do that if we multiply this waveform by root 3 and add it to this waveform you can do it yourself and you will find that i capital A has a waveform like this ok, you can do this exercise yourself. So, i capital A waveform is something like this ok.

You can see that i capital A is distinctly different from i as ok. So, if we had only a 6 pulse rectified with 1 is to 1 transformer then i capital A with both sides in star for example, then i capital A and i small a s these two would have been identical right. But, now in the presence of this star delta transformer we see that i as waveform and i capital A waveform is distinctly different ok; i capital A waveform has more number of steps like this with these values here.

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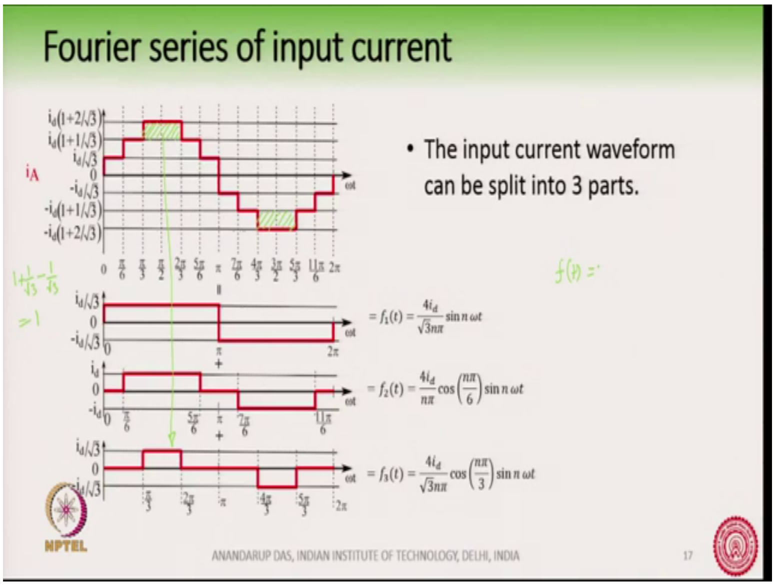

So, let us now analyze this waveform and find out what are the harmonics. Note that we are been doing this exercise to find out that whether we will get any improvement in the input current waveform i capital A ok. Really do we really get any improvement that is what we are trying to find out. So, if we see this waveform and we do a Fourier analysis of this ok. So, how can we do the Fourier analysis we can do it of course, we can do it by the symmetries and all, but we can also do it slightly intelligent way by splitting this waveform into 3 parts ok.

So, one part is this one here the other part is this one and the third part is this one. So, how do we how are we getting this. So, the first part this one is coming from this part of the waveform ok. So, this part of the waveform like this to this this part of the waveform. So, this is the first part of the waveform this part of the waveform is coming here ok.

So, you can see the magnitude. So, that this waveform is a square wave with amplitude of id by root 3 and minus id by root 3 here. So, this is the waveform which is coming here. So, this is the first part of the waveform what is the second part of the waveform. The second part of the waveform is this part of the waveform and this part here.

So, it is like this here; here and here. So, this part of the waveform is what is drawn here so this is the second part. So, the amplitude of this one is 1 plus. So, the amplitude is 1 plus 1 by root 3 minus 1 by root 3 and. So, the amplitude is 1 here. So, because it starts from 1 by root 3.

So, the amplitude is 1 plus 1 by root 3 minus 1 by root 3 and. So, the amplitude is 1. So, that is what we have said the it is a quasi square wave starts from pi by 6 and then it has an amplitude of 1 here ok. So, this is the second part of the waveform, what is the third part of the waveform the third part of the waveform is this part here. This part of the waveform which is again drawn here.

Ok. This is the third part of the waveform right. So, we can split the whole waveform into 3 parts and when we can quickly apply the formula that we had derived a little bit earlier what we had derived? We had derived that ft is ok. Let me go back and check this formula how did we write that formula.

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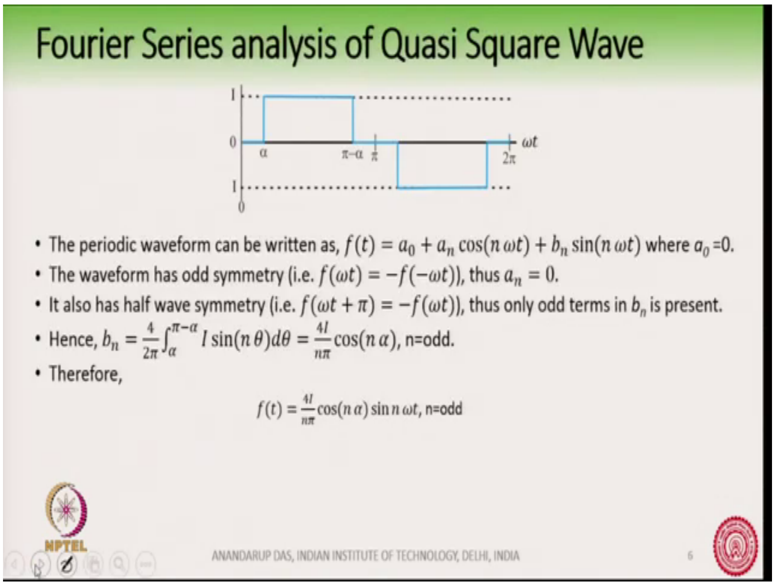

So, we had seen that ft is equal to 4 i by n pi cos n alpha sine n omega t; that was the generalized expression for an angle of alpha quasi square wave with alpha and pi minus alpha here. So, therefore we can write the Fourier series expansion of this waveform and this waveform and this waveform and then just add it up ok.

So, this waveform will have. So, the first waveform here. So, let me rub this off sorry. So, let me rub this off. So, the first waveform here has alpha equal to 0 degree and its magnitude will be 4 id by root 3 n pi. So, this is the first expression alpha is equal to 0 degree right. For the second one, for the second one what we find that the alpha is equal to pi by 6 and it is magnitude is 1.

So, 4 id by n pi cos n pi by 6 sin n omega t. So, this is the this is for the second waveform f 2 t is for the second waveform here. And what is about the third one? For the third one alpha is equal to pi by 3. So, cos n pi by alpha. So, cos n pi by 3 and the magnitude is 4 id by root 3 n pi here. So, 4 id by root 3 n pi cos n pi by 3 sine n omega t right. So, if we add all these 3 together.

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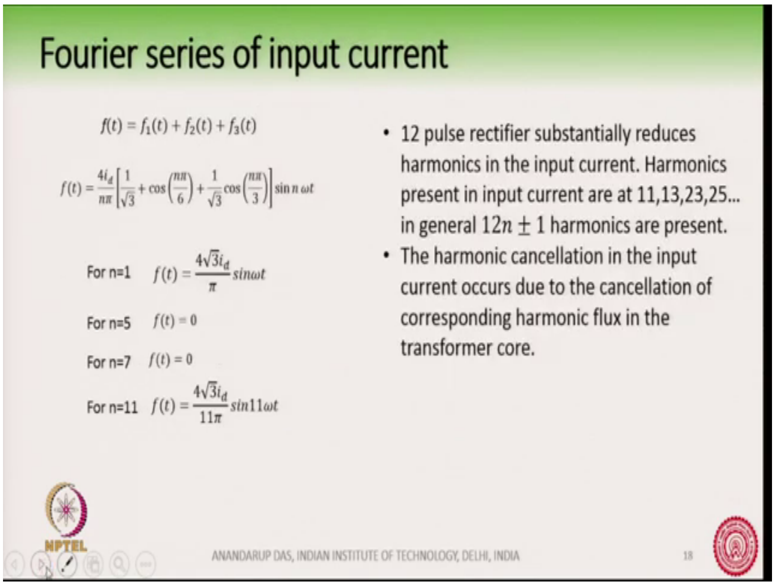

Then so, we get the total ft ft of the whole waveform. So, ft is f 1 t plus f 2 t plus f 3 t and. So, we write the total expression here of f t 4 id by n pi and this big expression here. So, if we put now n equal to 1 in this expression we will get the fundamental component in the input current waveform i capital A ok. So, n equal to 1. So, we get this is the magnitude of the fundamental ok. For n equal to 5 you will see that ft is equal to 0 and that is true also for n equal to 7 ft will be equal to 0; if you put n equal to 5 and 7 in this expression ok.

And not only 5 and 7, but any 6 n plus minus 1 where n is an integer will give the value of ft to be 0, you can put it and check it. So, we see that for any 6 n plus minus 1 harmonics. So, the input current will cannot have any 6 n plus minus 1 harmonics. So, n equal to 5 n equal to 7 where n is equal to odd 4. So, n equal to 17 and 19 then again n equal to 29 and 29 and 31 these harmonics will all be absent ok. Now for n equal to 11; if you put for n equal to 11 you will get again another value.

So, this means that the harmonics present in the input current are at 11, 13, 23, 25 and in general 12 and plus minus 1 harmonics are present ok. So, this 5th, 7th harmonics are totally absent this has a substantial effect on the input current distortion ok. As we had said earlier 5th and 7th harmonics have the maximum impact, because they are close to the fundamental ok. Now, in this case we see that the 5th and 7th harmonics are gone right also the 3rd order harmonics are also gone.

So, 3rd n equal to 3 if you put n equal to 3 that will also come out to be 0. So, therefore, n equal to 3, 5, 7, 9 all these 4 harmonics are gone in the input current waveform and the 1st harmonic that comes is at n equal to 11 ok; and then n equal to 11 and 13 and then it goes to n equal to 23 and 25 like that 35 and 37, 47 and 49 like that. So, in general 12 n plus minus 1 harmonics are present in the input current. So, this substantially improves the input current waveform profile ok.

Now, note that this harmonic cancellation in the input current is occurring because of the cancellation of the corresponding harmonic flux in the transformer core. Both the star and the delta windings are carrying the harmonic currents on the secondary side of the transformer. What happens is actually the cancellation of the harmonic fluxes in the core of the transformer you this you should understand that is why the input current does not have the 5th and 7th harmonics ok.

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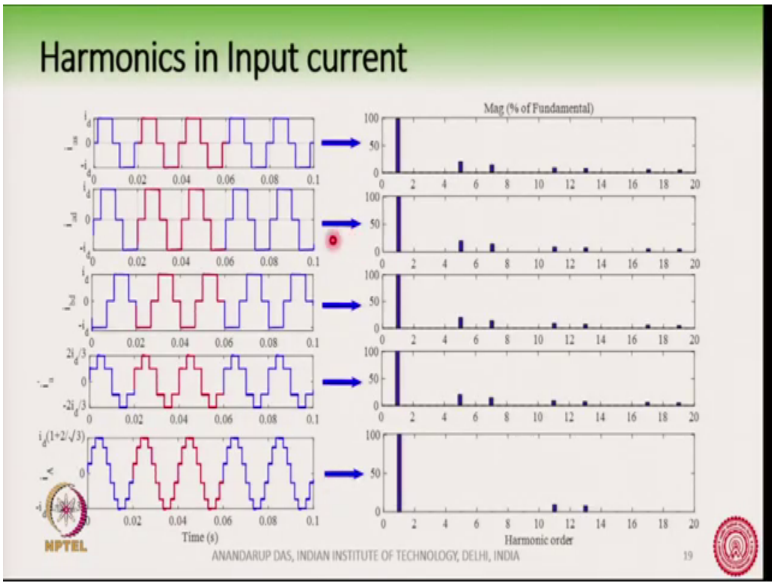

So, this is where we have shown the waveforms of i as and i ad and then you can see the harmonics are present in the star and delta waveforms that is what it is shown here, but in i capital A that is the primary input current the harmonics are 11th and 13th of that magnitude. Next we will see how can the harmonics be further improved ok; how can the harmonics be further improved.

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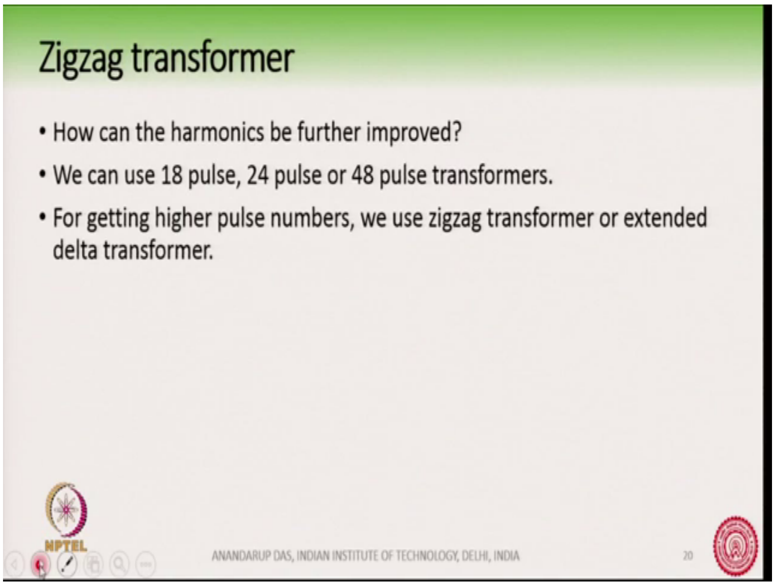

So, we can use in a similar way 18 pulse, 24 pulse, or 48 pulse transformers ok. Now for getting this higher pulse number so as we go to the higher pulses for example, if we go to a 24 pulse transformer then the first band of harmonics will reside at 24 n plus minus 1. So, 23rd and 25th is where the first harmonics will reside all other harmonics before 23rd will be totally absent.

So, that is an advantage in terms of the input current quality. Of course, it is a disadvantage in terms of the complexity of the transformer there is always a trade-off ok; between what is the how much improvement in harmonics we want to get and how much complex we would like to make our converter along with the transformer ok.

So, for getting this higher pulse numbers we can use the zigzag transformer or extended delta transformer ok. Now, let me before I proceed on the zigzag transformer let me.

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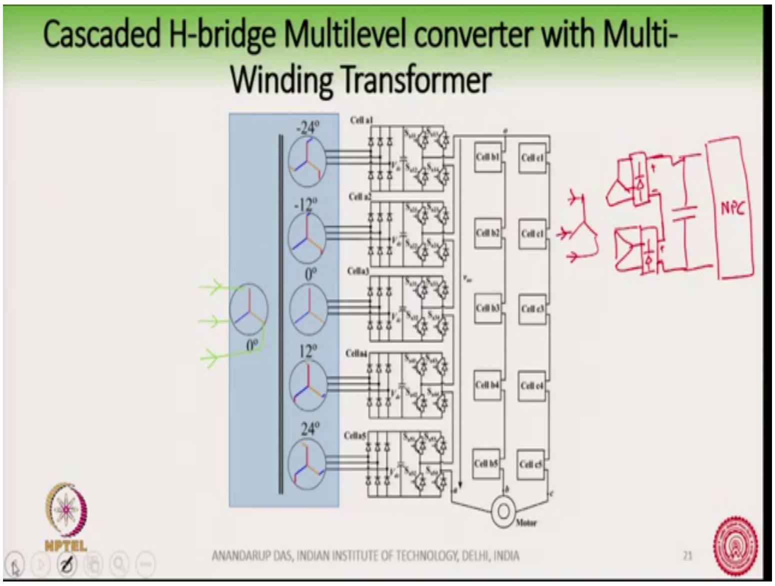

See or let me show you how the zigzag transformers or this multi pulse transformers can be used in a suppose a cascaded H-bridge converter. So, we had seen that cascaded H-bridge converters, had a large number of DC sources; isolated DC sources we acquired them isolated DC sources here. Now these DC sources can be are of course, fed from a diode 3 phase diode bridge rectifiers like this here. So, suppose we are showing here you the 5 cell version of the cascaded H-bridge.

So, you have 5 cells here all these 5 cells have an input rectifier, a DC bus and then we have h bridges here and they are connected on the ac side here. Now, what happens at the input side at the input side we can use a multi pulse transformer ok; we can use a multi pulse transformer. So, if we use such a multi pulse transformer then we can on the input side of this the current drawn from the input side that is this current here this current will be highly sinusoidal highly sinusoidal waveform ok. So, this is for example, like a this is 5 cells are there.

So, the input current will be well below the standards i triple e or i c standards harmonic distortion standards, thd will be way below. So, the in this cascaded H-bridge converter we had said that we require isolated DC sources that was a disadvantage we require isolated DC sources. So, we need a transformer with several secondaries that was a disadvantage. However, this advantage to some extent can be used to our advantage by making a multi pulse transformer here ok.

So, in if we use such a thing then the input current distortion can be substantially reduced ok. So, in a similar way the NPC the Neutral Point Clamp Converter we had seen that there was a DC bus and this DC bus can also be created from a star delta transformer ok. So, in NPC. So, we had seen that in NPC we had this DC bus. So, this was going to the 4 switch. So, this was the NPC converter. So, we can make a star delta transformer with rectifiers and can make a connection like this such that the input current this current here has substantially lower harmonics ok; this is possible ok.

So, when we talk about this higher pulse transformers we usually talk about zigzag or extended delta connections. So, we continue with the multiples transformer.

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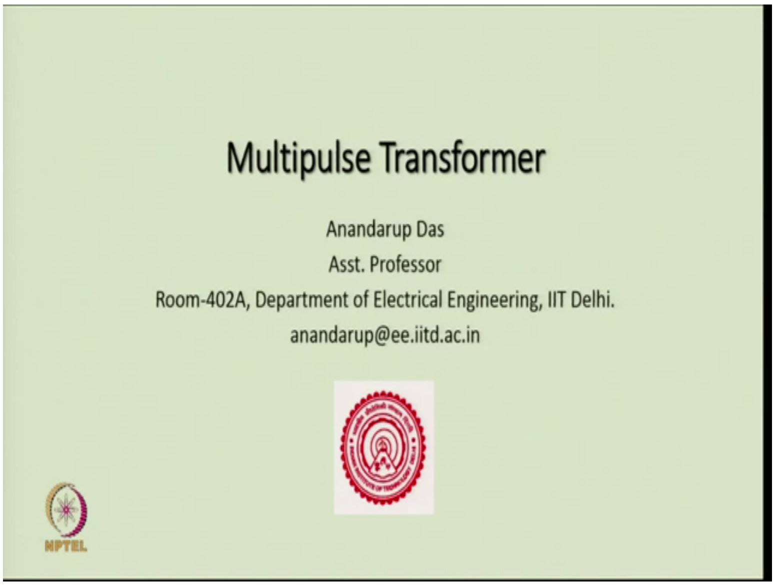

So, today's discussion will be on zigzag transformer and how the zigzag transformer helps in improves the input current harmonics. So, that is what we will study.

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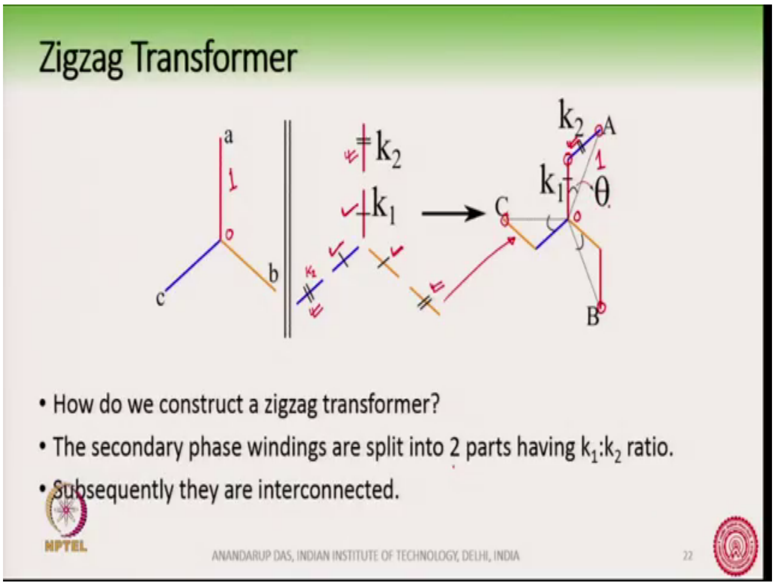

Now, here we see the zigzag transformer there is you can see here there is a suppose there is a tower connected primary and there is secondary 3 phase, but in this secondary winding in the secondary side of the transformer the windings are split into 2 parts ok. So, for example, you can see here that this is the r phase winding and the r phase winding is split into 2 parts and we can say that their turns ratio are k 1 and k 2 if this turns if this number of turns here is 1 we can say that this turns ratio is k 1 and this is the k 2 of the r phase. So, we have now physically split the r phase winding into 2 parts having turns equal to k 1 and k 2.

Similarly, we have also split the b phase and c phase into 2 parts having k 1 and k 2. We can do this always because this windings are on a code and we can have 2 windings like having k 1 turns and k 2 turns on the same limb. So, they are basically linking the same flux. So, we can draw then the diagram like this ok.

So, in order to make a zigzag transformer we subsequently interconnect these windings, but slightly in a different fashion ok. How do we connect it? See here, we first say take this winding k 1 this winding here, k 1 and put it here like this k 1. Similarly, we put we take this winding and we draw it like here what I have drawn here and we take this winding the blue one and draw it here and then we connect the one side of the winding to form the star point here ok.

So, we have taken this winding, this winding, so this winding, this winding, and this winding and we have formed this one this one and this one ok. Now, we take for example, this winding of the C phase we take this winding here and put it here and we connect them together.

So, we have connected them together here ok. So, this here this is having k 2 this comes here and is connected to the k 1 windings; k 1 turns of the A phase winding and k 2 of the C phase winding is connected. Similarly, you can take this winding and we can connect it here like this and we can take the B phase this k 2 winding and can put it here right.

So, once we do this what happens what we see then is that the voltage produced. So, if you take the voltage from this point here and here and here ok. If we extract the voltage from these points then what happens there is a particular phase shift between the input side voltage and the output voltage. For example, this is o point and this is also o point o small a and o capital A here suppose in the primary side we have o small a this is the primary voltage and o capital A this is the secondary voltage ok.

Once we have already interconnected. So, this o capital A this voltage will have a phase shift between them suppose we make o small a this magnitude is equal to o capital A right. Suppose, we make the voltage is equal, but then we see that there is a phase shift between the voltages of o small a and o capital. And, this is what the zigzag transformer does and how much is this phase shift this phase shift here is denoted by theta here ok; this is the phase shift and you can immediately recognize that this phase shift is dependent on the values of k 1 and k 2 right.

So, by changing the values of k 1 and k 2 the angle theta here. So, this is a triangle here with having k 1 and k 2 and I can assume for example, that this length is 1 where this length is also can be 1 or can be anything else also with that depending on the turns ratio we want or the voltage ratio we want from the primary to the secondary side.

So, therefore, this angle theta can be changed by changing the values of k 1 and k 2 ok. So, what does that mean if we split. So, how did k 1 and k 2 originate because we had split the winding into k 1 and k 2 parts ok. So, therefore, by changing the ratio of k 1 and k 2 I can change the value of theta here ok. So, this makes an advantage that this creates an advantage that this theta value is kind of like adjustable depending on the values of k 1 and k 2 chosen right.

So, this is a zigzag transformer ok. So, this is the star side and this is the zigzag transformer connection and the corresponding phasor diagram here ok. So, the amount of phase shift on the output of the zigzag transformer can be controlled or can be adjusted by changing the values of k 1 and k 2.

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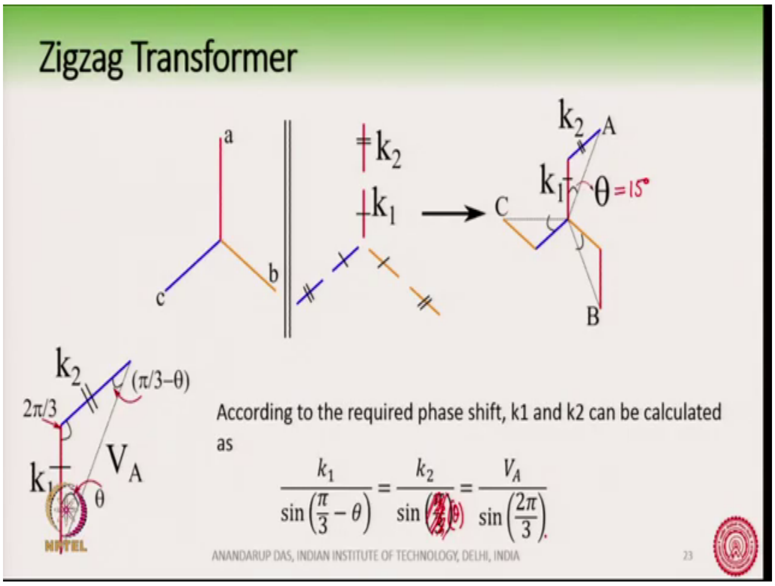

So, this is what is also shown here mathematically. So, you can see here we have we have drawn we have seen this diagram; we have seen this diagram. So, this is o A B C. So, you can find out the mathematical relation between k 1 k 2 and VA for example, this is the output phase voltage of the zigzag transformer.

So, then you can see k 1 by sine pi by three. So, this is the this is the triangle; this angle is theta this angle is 2 pi by 3 or 120 degrees and then this is 60 degree minus theta ok. And this sides are k 1, k 2 and this side suppose we define as VA that is the required line voltage required phase voltage magnitude. So, therefore, we can write k 1 by sine pi by 3 minus theta is equal to k 2 by sine pi by 3 which is equal to no there is a small mistake here. So, we should write it k 1, k 1 by sin pi by 3 minus theta is equal to k 2 by sin theta. So, this is not pi by 3 this is k 2 by sin theta ok.

So, there is a mistake here. So, k 2 by sin theta which is equal to VA by sin 2 pi by 3 ok. So, now we can find out what is the required k 1 and k 2 here in terms of VA. And so suppose we can have suppose we want a zigzag transformer with theta equal to 15 degree ok. Then we can find out what is the required value of k 1 and k 2 ok. If we want a theta equal to 7.5 degree then we can accordingly choose k 1, k 2 ok. So, we will split the phase winding into 2 parts this is the k 1 and k 2 parts.

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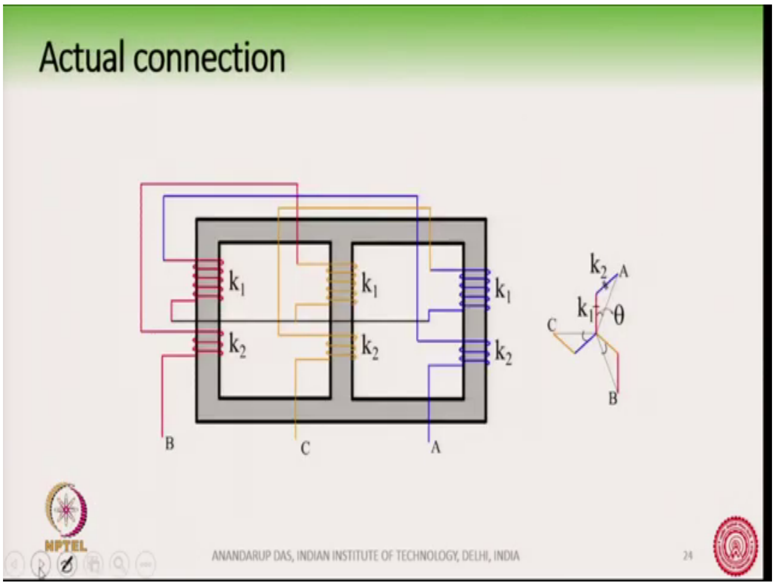

So, how do we actually do it in transformer is very simple actually. So, here you can see that is the r phase winding the total number of turns is k 1 plus k 2 which we have split into two parts k 1 and k 2 ok. And then we are now we are now in inter connecting. So, we have done this k 1 and k 2 for r phase for B phase and for so, for the 3 phases here ABC phases.

Now, we can interconnect as per this diagram here and then we will see that we are getting the required phase shift between the primary and secondary side of the transformer ok. So, this is the secondary side we have not shown the primary side; this is the secondary winding connections which is connected now in a zigzag fashion. So, this is how we actually do the circuit or we have to do the connection.

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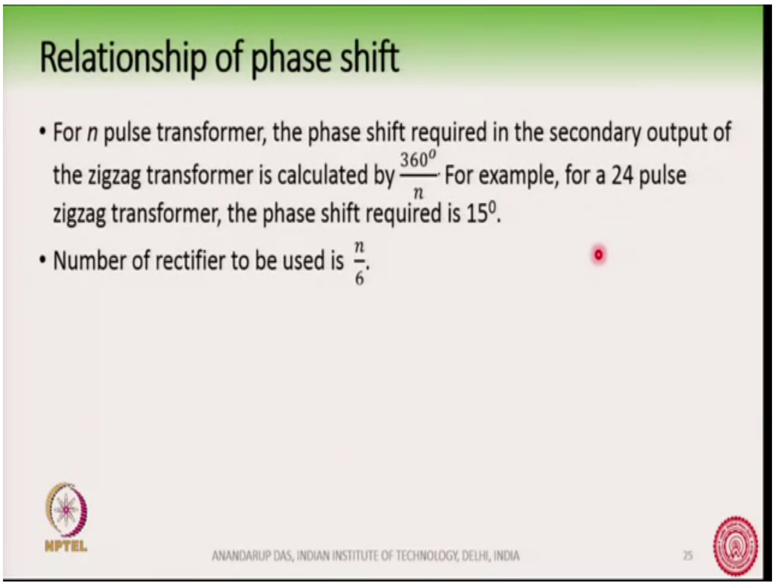

So, for n pulse transformer now coming back. So, we were talking about the 12 pulse transformer. Now, in case of a zigzag transformer suppose we want to get a 24 pulse transformer or in general. We can say that if we require an n pulse transformer the phase shift required in the secondary output of the zigzag transformer is 360 degree by n.

So, for example, for a 24 pulse zigzag transformer the phase shift required is 15 degree for a 48 pulse zigzag transformer; the phase shift required will be 7.5 degree that is 360 degree divided by n ok. And the number of rectifiers to be used is n by 6 for 24 pulse zigzag transformer the number of rectifiers is 4.

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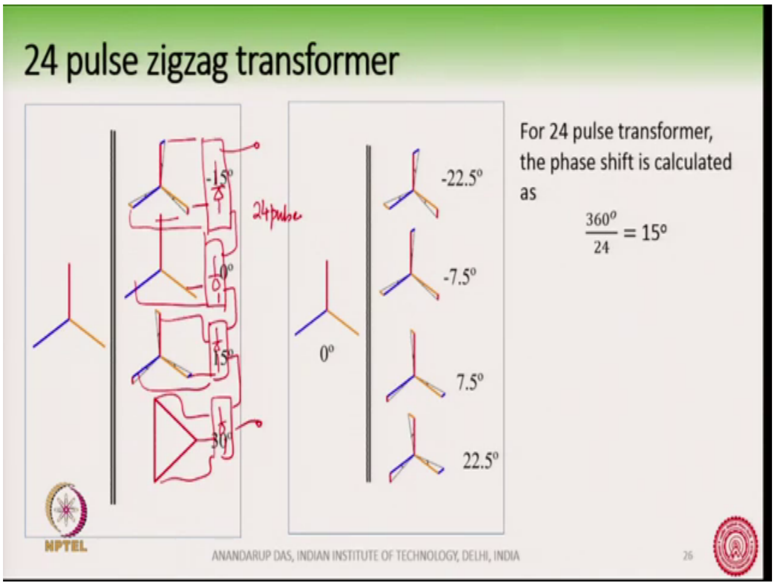

So, let me show you connection here, you see here 24 pulse zigzag transformer connection. So, here you can see that the primary is connected in star and there are 4 secondaries ok, why 4 secondaries because for a 24 pulse we require 4 secondaries each rectifier gives 6 pulse. So, that with this 4 4 secondaries of course, we have 4 rectifiers connected here we have not shown that.

So, if you see here these outputs are connected to rectifier ok; this output is again connected to a rectifier. Similarly, there is a rectifier and there is a rectifier here. So, there are 4 sets of rectifiers here right and these 4 sets of rectifiers they will be series connected ok. So, that we get 24 pulse voltage output here. So, each rectifier gives 6 pulse and 4 rectifiers will give us

24 pulse rectifier output right and so, what will be the phase shift angle what will be the phase shift angle? The phase shift angle will be 15 degrees ok.

So, we can have the star we can assume that star as a 0 degree. So, we can have one star connected transformer secondary having a 0 degree phase shift then we will have minus 15 degree plus 15 degree or 30 degree. Of course, 30 degree we can have with the delta ok. So, we need 4 transformers whose output voltages are phase shifted by 15 degrees

So, 1 transformer is the star which gives a 0 degree phase shift, one can be a delta which gives us a 30 degree phase shift, but we need two mode which we will get from two zigzag transformers one gives us a 15 degree phase shift one gives us minus 15 degree phase shift in this way we will be able to arrange for a 24 pulse transformer rectifier arrangement.

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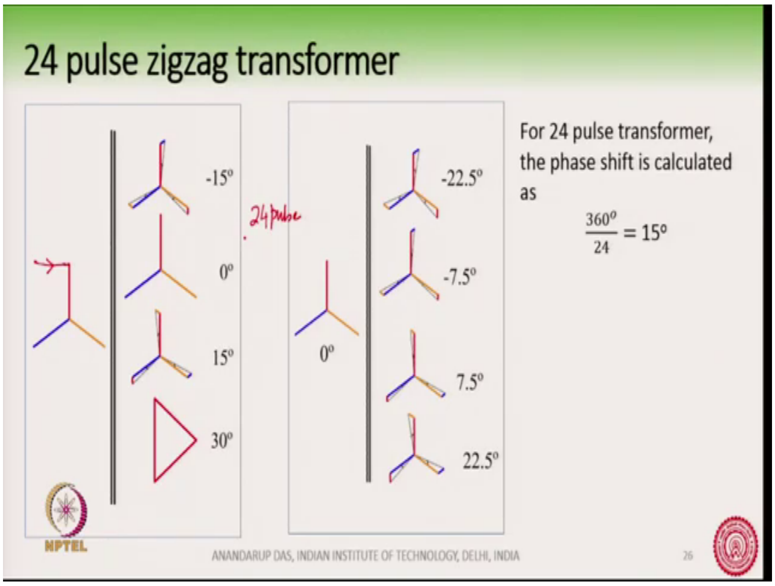

So, what is the advantage of the 24 pulse the advantage is that this current input current will have harmonics the first harmonic will come at 23rd harmonic, 23rd, 25th, 47, 49 like that no other harmonics will come on the input side input current ok. Another way, of so there may be multiple ways of generating the 24 pulse. So, you can have the primary connected at 0 degree you can also have the 4 zigzag transformers on the secondary instead of 5 zigzag as I have shown here.

So, if you have 4 zigzag transformers on the secondary you can have 22.5. So, 22.5, 7.5, minus 7.5 and minus 22.5 degree angles note that the difference is 15 degree between these outputs ok, but this arrangement is more symmetric as compared to this ok. This is more symmetric. So, it actually the stress on the transformer for a more symmetric arrangement is less in particular during short-circuit condition of the transformer there is a stress on the transformer and due to the short circuit current and this the mechanical stress on the windings can be more symmetric.

If we have a more symmetric output on the zigzag transformer ok. So, preferably this connection may be used ok.

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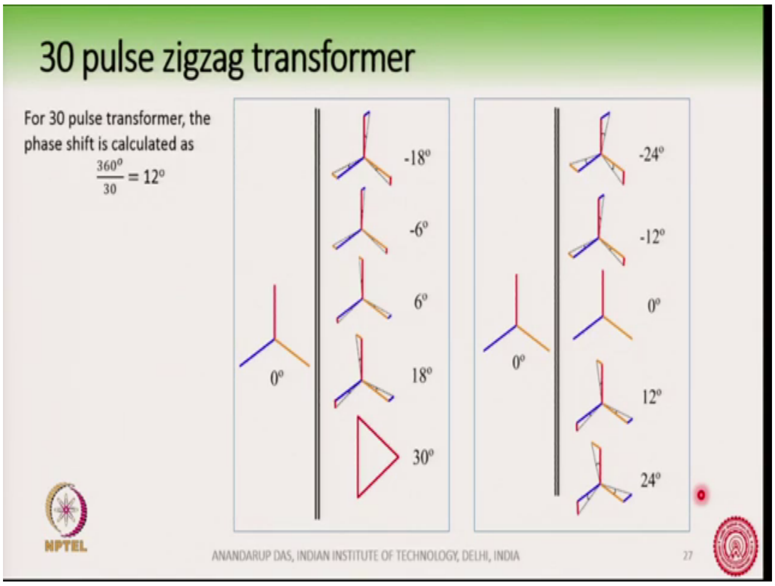

So, in a similar way we can also have a 30 pulse zigzag transformer. So, with 30 pulse zigzag transformer the phase shift required is 360 degree by 30. So, 12 degree and how many we will need how many rectifiers zigzag transformer or how many rectified transformer? We need 5 because each rectifier produces 6 pulse. So, for 30 pulse we will require 5 such sets. So, then you can have different types of arrangement like 0 degree here, then you can have 6 degree minus 6 degree minus 18 degree, 18 degree and 30 degree ok.

So, 12 degree gap between them or you can have 0 degree and 0 degree like this can have minus 12 minus 24 or plus 12 and 24 degrees ok. So, this is how the zigzag transformer can be helpful for creating the phase shifts right. So, it is like the construction is quite simple because it is only a matter of changing the values of k 1 and k 2 in order to change these angles. So, this angle is for example, 24 and this angle sorry this angle is minus 24 degrees and this angle can be minus 12 degrees and you can see from the diagram here that the k 1 and k 2 ratios are changing here we have changed the sequence also 12 degree.

And so, by observing this one you will be able to find out how much phase shift is required.

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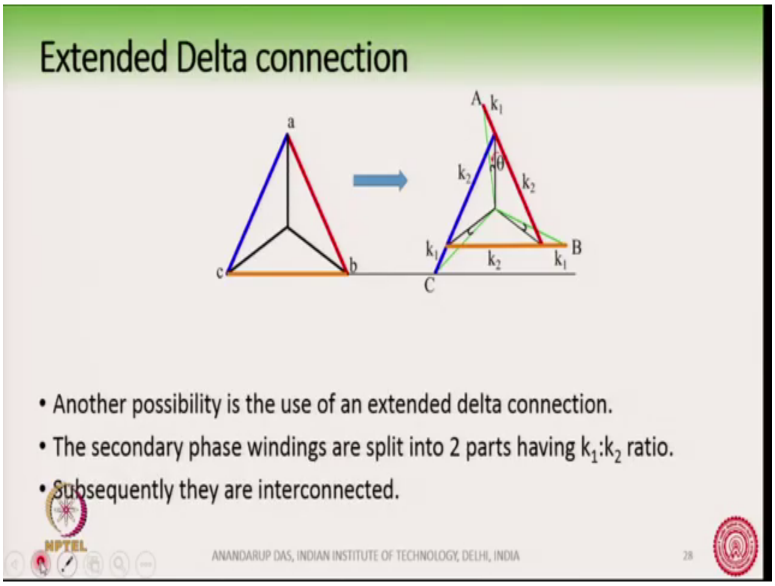

Now, we will talk about another transformer which can also produce this phase shift which is the extended delta transformer ok. So, the in extended delta transformer also the secondary winding is again split into 2 parts k 1 and k 2 and subsequently they are interconnected in case of a zigzag transformer this interconnection happened with one side connected in star in an extended delta this other possibility comes up.

And, you can see here this is the secondary winding again you have a k 1 and k 2 split that blue colored; this is the winding it is split into k 1 and k 2 parts. This one is split into k 1 and k

2 parts and this one is also split into k 1 and k 2 parts. And, now if we take and so, the connection is like it is made like this here. So, this phase comes and connects here this phase comes and connects here.

So, then again we find that the theta angle between the voltage at point A and the voltage at small point a here the there is a phase shift between the primary and secondary side ok. And so, this theta angle can again be controlled by choosing values of k 1 and k 2 and changing the ratio ok. So, extended delta and zigzag are basically following the same principle where we change the where we split the windings into 2 parts k 1 and k 2 and then reconnect ok.

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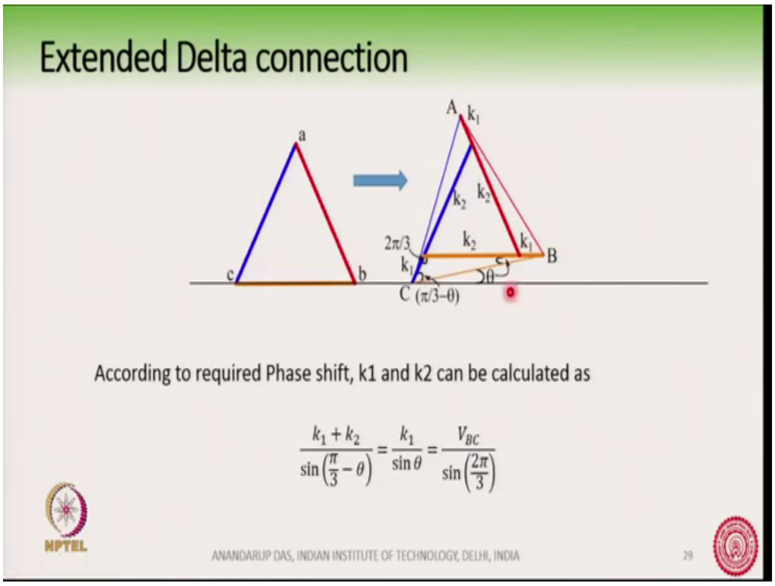

So, you can find out similarly what is the values of k 1 and k 2 as you can see here again we can follow the sign formula and can find out what are the values of k 1 and k 2 required to produce the desirable phase shift.

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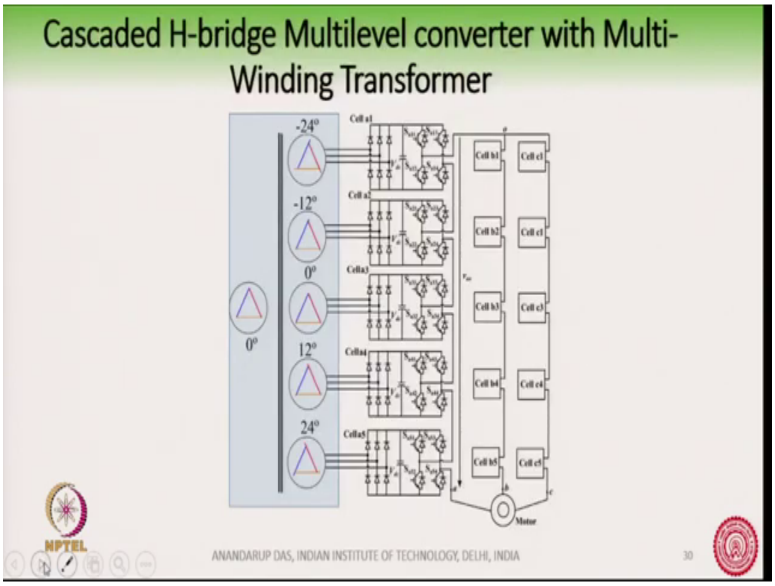

So, let us now see how this extended delta can be used in a CHB you can see here in this 5 cell CHB we have 5 rectifiers here; 5 rectifiers. And, these are supplied from the secondaries of this extended delta connected transformer the primary may be in delta maybe in star ok.

One advantage of having an extended delta is that there if there is any unbalanced that unbalanced current can flow inside the delta ok. The third harmonic or triple in the 0 sequence current can flow inside the delta winding, but here you can see there are 5 windings, 0 degree minus 12 degree minus 24 12 and 24 ok.

So, this is one of the possibilities of making the connection of a cascaded H-bridge. So, far we had not talked about the input side; now we are talking about what can be a possibility on the input side. The advantage of this is that the input current waveform which we will draw from here this waveform will be having very less magnitude of harmonics ok. So, this is the extended delta connection.