DC Power Transmission Systems
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Lecture - 08
Converter configuration for pulse number equal to 6

In the last class we were discussing 2 figures of merit; one is the value utilization factor and the other one is transformer utilization factor, both these factors have to be minimized. So, let us see how to choose these values for a given value of pulse number.

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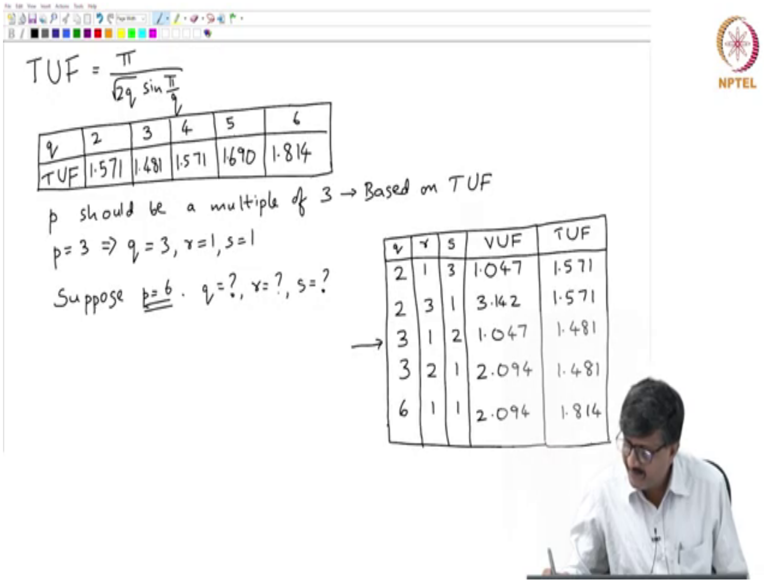

So, if I try to recall what was the expression for the transformer utilization factor TUF; the expression is pi by under root 2 q sin pi by q. So, TUF is dependent only on q and q is a positive integer greater than or equal to 2 ok.

So, that is what we have been restricting the value of q 2. So, one can see that TUF is minimum when it is equal to 3 So, what I will do is I will try to give the value of TUF for different values of q. Suppose I take different values of q and also get the values of TUF So, are the first value of q is 2 so, our q is equal to 2 TUF can be calculated it is 1.571, for q is equal to 3 just substitute in the expression 1.481, for q is equal to 4 it is 1.571.

For q is equal to 5 it is 1.690 q is equal to 6 it is 1.814. So, we see that it can be verified by substituting different values of q, what is the value TUF. So, q is equal to 2 gives 1.571 and the next value of q that is 3 gives a lower value. Then after that a higher value of q gives higher value of TUF, now as q increases the value of TUF continues to increase this can be verified ok. So, the optimum value of q is 3, so, q is 3 is something which is a coincidence because our ac systems or 3 phase systems ok.

So, we can say that p should be a multiple of 3. Now, this is only based on TUF, see please note this result is applicable based on TUF. Now, we have to verify whether the value utilization factor will give a different a choice for q and hence a different choice for p ok. So, sorry this is based on based on TUF. So, if the pulse number p is equal to say 3.

Then this means the optimum values of q r and s are, q equal to 3, r equal to 1, s equal to 1. Now, let us just make our choice by taking this value of 3 which is obtained based on TUF. So, if I say based on TUF p should be a multiple of 3, the first possible value of p is 3 itself, the second possible value is 3 into 2 ok.

Suppose, p is equal to 6 then, the question is; what should be the value of q? What should be the value of r? What should be the value of s? Now the only hint we have got so far is for the value of q. So, there are I mean where we saw that q should be a multiple of 3 base that is based only on TUF. So, either it can be equal to 3 or equal to 6 ok, but still we should not rule out other choices for q because this result of p being multiple of 3 is only based on.

Student: TUF.

TUF, it is not based on the other utilization factor. So, let us try to consider all possible choices. So, all possible choices of q r and s which will give a p equal to 6 so, let us form a table. So, I will try to show all possible cases, which will give me p equal to 6. So, I will try to I will try to consider different values of q r s and such I mean these values are such that the product of these 3 values is equal to 6.

So, my intention is to get p equal to 6 ok. So, let us see for the different choices of q r s which will give p equal to 6 the values of value utilization factor as well as transformer utilization factor. So, how many possible choices are there for q r and s for this given value of p which is 6? So 6 choices let us see. What are the possible choices of q? See q has a constraint it should be greater than or equal to 2 ok.

So, q is always greater than or equal to 2 r r and s are greater than or equal to 1 and all are integers all are positive integers. So, let me take this least possible value of q, now please note I am taking q equal to 2 this is because the earlier result of a q equal to 3 it was only based on TUF. So, if q is equal to 2 then I can have r equal to 1 and s equal to 3 so, that p is equal to 6 or I can also have r equal to 3 and s equal to 1 ok.

Now these are the only 2 cases with q equal to 2, the next possible value of q is 3. So, if q is equal to 3 then the possible values of r and s 1 and 2 or 2 and 1 so, 312 321, any other possible value of q?

Student: 6.

6, so, if this q itself is 6 r and s should be 1 so, that p is equal to 6. So, these are the only 5 possibilities for p is equal to 6. So, for each of these 5 possibilities let us see what is the value of VUF, what is the value of TUF, so, I will just give you the values we have the expressions. So, this is 1.047, 1.571, 3.142, 1.571, 1.047, 1.481, 2.094, 1.481, 2.094, 1.814.

So, if you look at the last two columns, these two columns give the value values of the two figures of merit that we are trying to minimize. So, if you look at the value utilization factor, the least value of value utilization factor occurs for two cases, the least value is 1.047. So, 1.047 is occurring for q equal to 2 r equal to 1 s equal to 3 and its also occurs for q equal to 3 r equal to 1 s equal to 2.

Now, if you look at the transformer utilization factor that is the last column, again there are two cases in which TUF is minimum the minimum value 1.481 there are two cases. Now, the two cases for which minimizes VUF are not the same as the two cases which minimize TUF, but there is one case with q equal to 3 r equal to 1 s equal to 2 which minimizes both VUF and TUF.

So; obviously, this is the best choice for q r and s for the given value of p that is 6 ok. So, now, let us say what is the circuit for q equal to 3 r equal to 1 s equal to 2 so, that I will try to draw the circuit only for this case. So, we are not interested in the other cases because they are not resulting in optimum values of the 2 figures of merit. So, from now on when I consider p equal to 6 the only possible values of q r and s are 312 respective. So, let me try to draw the circuit ok.

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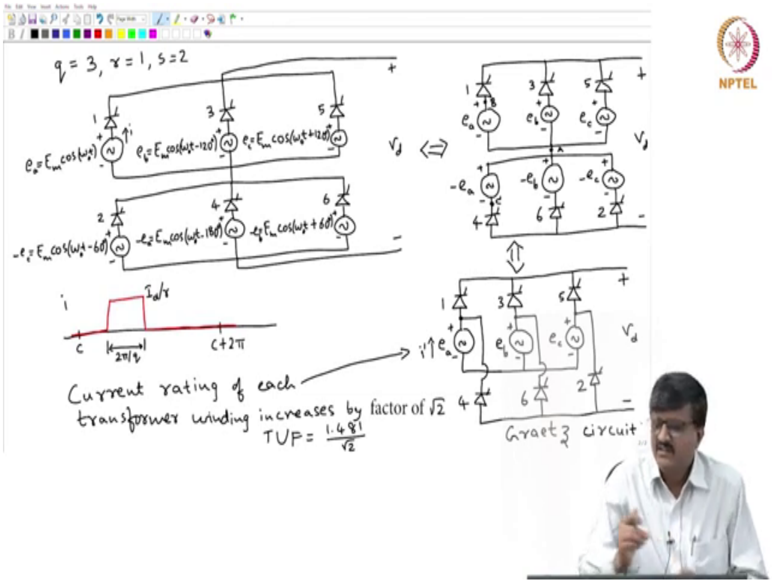

So, for the sake of simplicity what I will do is I will draw the voltage source I will show you a voltage source in the circuits diagram, though we know that in practice the voltage is obtained as the emf across a transformer winding ok. So q is equal to 3, r is equal to 1, and s is equal to 2. So, this is the same as the case that we saw many which minimizes VUF or TUF.

So, there are 2 commutation groups basic commutation groups that are connected in series, s is equal to 2 means 2 commutation groups connected in series, since r is equal to 1 there is only 1 parallel path ok. And each in each commutation group there are 3 thyristor valves or 3 voltage sources. So, if I try to draw the circuit diagram; so, this is one commutation group, there is one more commutation group connected in series with this.

So, I bring out 2 terminals which are the terminals of the dc side and the voltage across the this is v d ok. So, let me give some name for these thyristor valves, but before that let me try to give the expression for the voltages. So, suppose this voltage is E m cos omega o t. Now, if I take 1 commutation group in which there are three sources the voltages should be displaced by.

Student: 120 degrees.

120 degrees 2 pi by 3 that is 120 degrees. So, this voltage will be E m cos omega o t minus 120 degrees and this voltage is E m cos omega o t plus 120 degrees. Now, there is one more basic commutation group there are three sources in that commutation group as well.

So, the voltages of these three voltages in the second commutation group also are displaced by 120, but there these voltages are not in phase with the original voltages that is the voltages of the first commutation group. So, what will be the voltage of the voltage source in the second basic commutation group let me take the first voltage source. Of course, the peak values are all same E m.

Student: E m cos omega t plus pi.

Plus.

Student: Pi.

Pi.

Student: Pi.

Pi.

Student: (Refer Time: 14:51).

Say if I have six sources in this circuit, I have six sources. So, if I want a wave form which is close to ideal, see our ideal wave form is always a constant voltage for the dc side voltage v d. See v d is having a desirable voltage which is constant, now I cannot achieve constant voltage, but I can achieve the best possible waveform for v d. So, if I want to do that what should be the phase angle difference between the six voltage sources.

Student: 60 degrees.

60 degrees it is 360 by 660.

So, I should select the phase angles of the voltages of the second commutation group, such that the phase angles of the 6 voltages or displace by 60 degrees, but still if you take the individual basic commutation group the phase angle difference is 120 degrees. So, what should be the voltage of the first voltage in the second basic commutation groups E m cos omega o t minus.

Student: 60 degrees.

60 degrees, then the second voltage is E m cos omega o t minus.

Student: 180 degrees.

Sorry minus 180 degrees. And the third voltage is E m cos omega ot plus 60 degrees ok. So, let me give some names for some of these voltages, suppose I call this voltage as ea see this abc are letters used for the three 3 phases. So, e with a subscript a means a phase voltages I mean 1 cancelled I will call this as eb ok.

And this is ec, now I will not give a special name for the next voltage that is in the second commutation group there is the voltage E m cos omega ot minus 60 degrees. Now can I write that in terms of 1 of the notations ea eb ec can I write it in terms of the already used notations the ea eb ec.

Student: (Refer Time: 17:25).

Ok that is one way of doing, but let me go to the second voltage E m cos omega ot minus 180 degrees can I say that is minus ea. So, this is minus ea I will come to the first voltage, this is minus ea. Now let us come to the first voltage E m cos omega ot minus 60 degrees can I write that as negative of some already use notation minus.

Student: Minus ec.

Minus ec. So, this is minus ec and E m cos omega ot plus 60 degree is minus eb. So, this is minus eb ok. Now I will try to do some manipulations by just altering the positions of the thyristor and the voltage source, say when I have a thyristor connected in series with the voltage source ok. So, as long as it is a series connection if I interchange the positions the circuit working will not change. See if there are two components connected in series if I interchange the positions of their two components so, they circuit still performs in the same way.

So, what I will do is I will try to slightly alter the circuit ok. So, I will say that this is equivalent to so, I will draw one more circuit diagram. So, this is the first basic commutation group, the voltage here is ea voltage here is eb the voltage here is ec. So, I will give some names for the thyristor valves also I will complete this diagram. So, suppose I call this 1 by thyristor valve 1.

Now, I will go to the next voltage waveform which is immediately lagging ea. So, it is not eb it is minus ec, say the phase angle of minus ec is minus sixty. So, I will call this thyristor as thyristor valve 2 ok. Then the next voltage is minus 120 the next 1 which is lagging minus ec is eb so, I will call this three ok. Then the next voltage which lags eb minus ea that is 4, and the next voltage is this 1 ec and then minus eb which I will call this 6 ok. So, here I have 1 3 5 as it is and the connected voltages are ea eb ec as it is.

Now, come to the second basic commutation group. So, what I will do is I will interchange the positions of the thyristor valve and the voltage source. So, I will first put the voltage source, and then the valve right. Now there are three parallel paths, so, there are three voltages minus ea minus ec minus eb and the thyristor valves 2 4 6 ok. So, one of the voltages is minus ea so, I will show minus ea. Suppose, this is minus ea see minus ea is appearing in the first circuit as the second branch second parallel branch, but I am showing it in the as a first branch because all these are connected in parallel ok.

So, what is connected in series with minus ea which thyristor valve 4. Then there is a voltage minus eb and the valve that is connected in series with minus eb is 6. And there is a voltage minus ec and the valve that is connected in series with the minus ecs and of course, the voltage across the two dc side terminals is vd ok. Now I say that the second circuit diagram is equivalent to the first circuit diagram.

The only changes in the second basic commutation group I mean just an interchange the positions of valve 1 thyristor valve and the voltage sources that's all ok. Now how does that matter ok, let us see how does this matter. So, for that I need to draw one more equivalent. So, I will retain the circuit of the first basic commutation group as it is. So, I have thyristor valves 1 3 5 and they are respectively connected in series with the voltage sources ea eb ec.

Now, if you look at the second the basic commutation group which consists of thyristor valves 4 6 2 connected in series with minus ea minus eb minus ec respectively. Now you take the thyristor valve 4, the cathode of 4 is connected to the negative terminal of minus ea ok. So, let me give some names suppose I call this terminal as say terminal a I call this terminal as say terminal b I call this terminal as say terminal c some names upper case abc are ok. Now what is the potential of terminal c with respect to terminal a. See minus ca is the potential of a with respect to c minus ca is the potential of a.

Student: a with respect.

With respect to c what is the potential of c with respect to a.

Student: ea.

ea, So, that is as good as the potential of b with respect to a. So; that means, b and c are at the same potential, I will repeat potential of a with respect to c is minus here because plus is at a minus is at c. So, our potential of a with respect to c is minus ea. So, potential of c with respect to a is negative of that is ea. So, that is nothing, but the potential of b with respect to a. So; that means, b and c are at the same potential.

So; that means, even if I short b and c, when the I mean circuit will work as as it was working original. So, what can I do I can actually eliminate one of the sources say there is no point in connecting two voltage sources in parallel. Two equal voltage sources in parallel I mean I can just reduce it to one voltage source. So, what I can do is connect this cathode of the thyristor valve 4 to b directly. So, what I see this is b. So, I take this terminal b and connect it to the cathode of 4, is that ok.

Now a similar explanation can be done even for the second path and the third path. So, I can say that this is equivalent to connecting this terminal positive terminal of eb can be connected to the cathode of thyristor valve 6. And the positive terminal of ec is connected to the cathode of thyristor valve 2, is this ok. So, the two dc side terminals are brought out here the voltage across the dc side is v d.

Now, what did you achieve by doing these manipulations. Say though these circuits contain voltage sources in practice they are e and emf induced in transformer windings. So, their transformer windings now by getting this third circuits, say I started with the original circuit from the in the third circuit you see three voltage sources in the original circuit there were 6 voltage sources.

It essentially means; I can show that a circuit with six transformer windings is equivalent to a circuit with only three transformer windings though. So, I do not need 6 transformer windings I need only 3. So, what will be the effect on transformer utilization factor due to this? It gets reduced by how much? It is tempting to say half, but the number of windings get reduced by half, but the current rating what about the current rating.

See I have reduced the number of transformer windings, but by reducing the number of transformer windings what I mean what is actually happening here is? Currenting current rating increases, but what was the wave shape of the current through the individual transformer winding?

Student: (Refer Time: 29:10).

It is a constant for a certain duration equal to id by r and for the rest of the time is zero if you take any one cycle see the wave form is like this. Suppose so, if I take one cycle. So, I can always find a value c such that the wave shape of the current through the transformer winding is like this where it is equal to Id by r for a certain duration and it is equal to 0 for rest of the duration in the period. So, this duration is, this duration is I mean the in the original circuit I am talking about the original circuit.

Student: 2 pi by q.

2 pi by q 2 pi by q. So, suppose I take a the current here as I. Now suppose I take the revised circuit, I take the current here as say I prime, I prime agree. So, current rating of each transformer winding increases by a factor of root 2. Now, I am talking about this circuit the current rating of each transformer winding in this circuit, and the last circuit that I derived, for this circuit TUF is equal to the value that was obtained. So, the value was 1.481, 1.481 divided by root 2.

So, there is a reduction in the transformer utilization factor. So, this is possible by manipulating the circuit so, what is this a circuit I mean are you familiar with the circuit.

Student: (Refer Time: 31:07).

Yeah, this circuit has a name it is called Graetz circuit, maybe there are many sources which start from this circuit, but this circuit is not obvious say what we started with was an obvious circuit we started with 1 thyristor valve 1 ac voltage source ok. Then we tried to connect many such things in parallel then many such parallel combinations in series many such series combination parallel so on. So, what we started with something which are obvious, but Graetz circuit is not something obvious, I mean I mean its not obvious why you should work ok.

So, actually Graetz circuit is derived it is not something which has which till come just at once you know. So, Graetz circuit is in fact, derived from something which is more obvious ok. So, normally it is not drawn this way I mean if you try to look at this circuit I mean; the this is not a way in which it is drawn normally so, we draw it like this.

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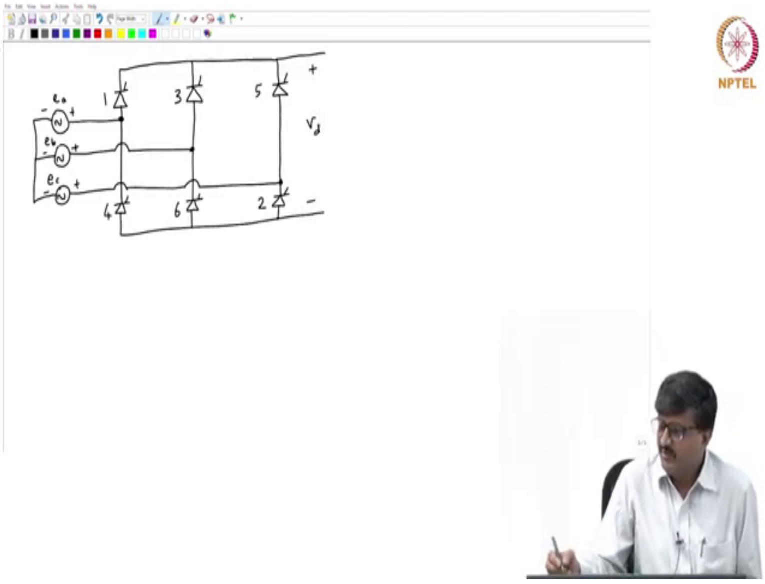

So we show what is known as a leg so, there are 3 legs, and there are three voltage sources. So, this voltage is ea so, I am just redrawing the circuit that we just now obtained. So, these three voltages are ea eb ec and there are it displace by 20 degrees and the name of this thyristor valve is 1 this is 3 this is 5. Forgot this one this is 4 6 2 and I have a dc side with 2 terminals the voltage across the dc side is vd.

So, this is how it is drawn usually ok. So, this is the Graetz circuit which can be derived from a circuit to are combinations of circuits that are more obvious. Now, this is a very ideal circuit because the transformer emfs are shown as voltage sources, but in practice there is something which we cannot ignore that is the leakage inductance ok. So, many times we will consider the circuit, so, I will go to the next page our converter circuit for p equal to 6 is just this.

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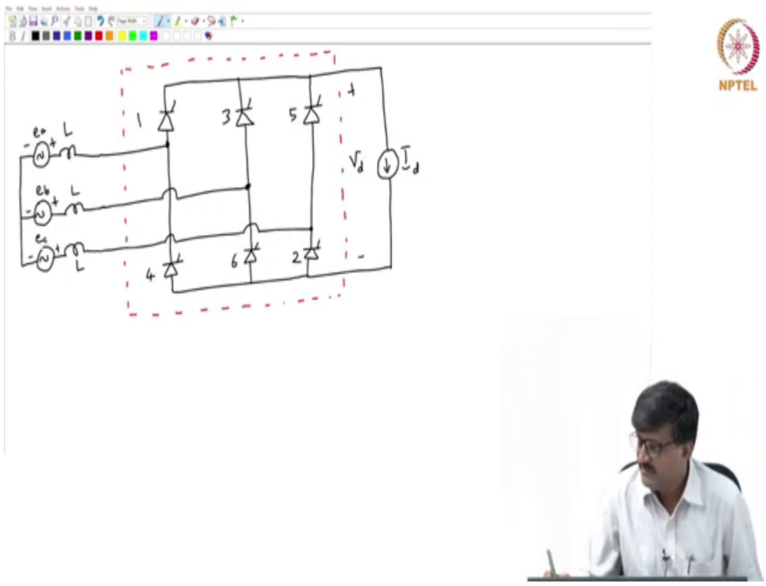

So, I have 3 legs. So, the converter consists of just 6 thyristor valves. So, 6 thyristor valves from the converter and you can easily show see that there are a distinguishable ac and dc sides, the 3 wires on the left from the ac side and the 2 wires shown on the right from the dc side. So, what we will do in this course is we will assume that the ac side; that means, whatever is connected on the ac side has a simple circuit, and there is a circuit for what is connected on the dc circuit.

So, we will start with some very simple circuits for what is connected on the ac and dc sides as far as this course is concerned. So, we will assume that the ac side is represented by a voltage source in series with a an inductance in each phase. So, there is an inductance l in each phase and of course, there are a 3 phase balanced voltage source ea eb ec.

So 3 phase balance sinusoidal, now one should note that this converter is only this much see when I say converter I am only talking about this for the time being, whatever is in this red dash line is the converter. And whatever I have shown beyond this is the representation of what is connected on the ac side or dc side.

Now, on the dc side as far as this course is concerned for the time being we will assume that there is a very large inductor on the dc side. So, the inductor will act as a filter for the current so, due to which the current is a constant. So, current is constant means I can just represent the current by a source. So, I will call this current Id of course, there is a voltage here v d the voltage the instantaneous voltage is v d, but the dc side is represented by a current source.

So we will spend a few classes on analyzing this a particular converter. So, please note whatever is marked in the red dash box is the converter, and the current source on the dc side is a representation of what is there on the dc side. And a voltage source in series the three phase voltage source in series with the inductance l in each phase is a representation of what is there on the ac side. What exactly comes on the ac side and what is there on the dc side let us come to that much later, now for the sake of simplifying our analysis we will make a very simplifying assumption of these circuits on the ac and dc side.

Now, we will spend some time on this, but we will spend a just one class or at least slightly more than that on a much simpler circuit for the sake of simplicity. We will start with the for the sake of simply I mean simplifying the first circuit that we analyze we will make l equal to 0. So, if l is equal to 0 the circuit becomes even more simpler ok. So, we will of course, we will consider l, but we will start with a very simple case l equal to 0. So, if l is 0 then there is only a voltage source on the ac side.

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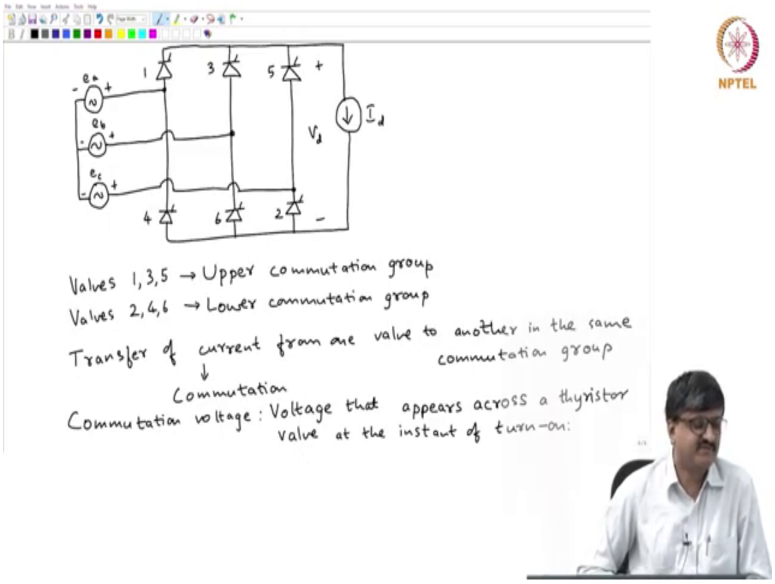

So, you see that there are 6 valves, but we has I mean as we know from the previous explanation there are two basic commutation groups. See valves 1 3 and 5 they form 1 basic commutation group valves 2 4 6 form another basic function commutation group. So, this basic commutation group consisting of valves 1 3 5 is called upper commutation group, upper commutation group and valves 2 4 6 form the lower commutation group.

So at any instant only one of them is conducting, now please note this is in agreement with the original circuit which was very simple I mean there was only voltage and thyristor valve. Now, just in the previous circuit I have showed inductor also so, there is an inductance l in each phase, but the presence of an inductance make the circuit complicated. So, if there is no inductance as in this case at any instant there is only one thyristor that conducts among 1 3 5 and at any instant there is one only thyristor that conducts among 2 4 6 ok.

So, there is some instant at which the transfer of current happens from one thyristor to the other in the same commutation group. So, the transfer of current from one valve to the other is known as commutation. So, we use the word, commutation to mean transfer of current from one valve to another in the same group in the same commutation group. So, this is called commutation. So, the word commutation is actually used to mean this, and there is a term known as commutation voltage. So, we will be using this many times commutation voltage means that is the voltage which appears across the valve at the instant of turn on.

So, voltage that appears across a thyristor valve at the instant of turn on so; that means, each thyristor valve has a commutation voltage; that means, the 6 thyristor valve. So, there are 6 commutation voltage 1 for each. So, we will start with this simple circuit we will try to analyze this in the next class. So, there a few things to be talked about in the circuit so, once we are approve with this circuit then we will go onto the next circuit with inductance ok.