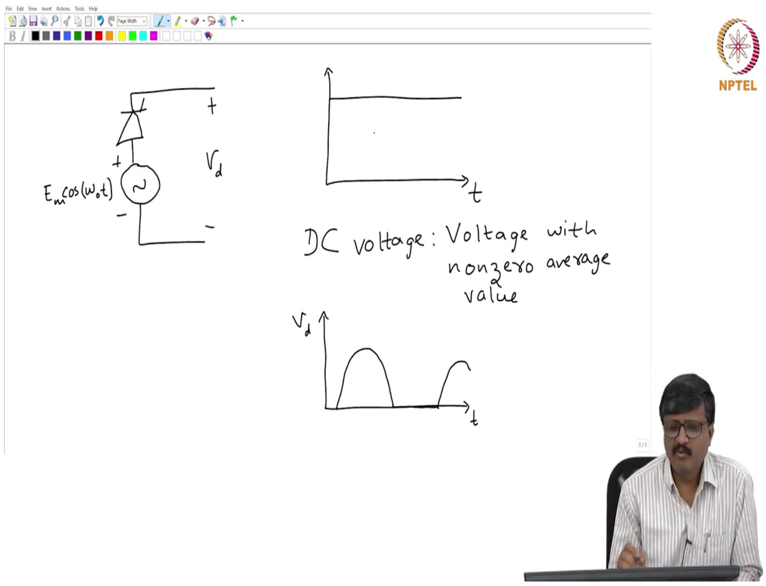
DC Power Transmission Systems
Prof. Krishna S
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture - 05
General Converter Configuration

What we will do in this class is try to derive a circuit which can be used as a converter. So, we saw some devices diode, thyristor and controllable devices. So, we will try to use the thyristor and see how we can get a converter using thyristors. And of course, since there is thyristor there is some amount of control, ok. Now the simplest converter one can think of is a circuit like this. I have a thyristor.

(Refer Slide Time: 00:49)



Now, suppose I connect a sinusoidal voltage source. Now, this itself acts as a converter where I have distinguishable AC and DC sites. Suppose, I take the voltage across these two terminals as V d V for instantaneous voltage the subscript d stands for DC. And these two terminals which are the terminals of AC voltage source are actually the terminals of the AC side. So, let me call this instantaneous AC side voltage as E m.

So, m subscript m stands for maximum, cos omega o t t is time omega o is the angular frequency. So, its a radian per second. So, if I have the frequency as 50 Hertz then it is 100 pi radian per second, ok. So, there is a distinguishable AC and DC side. So, the converter is just one thyristor and what I have is a AC side, a source which is having an instantaneous voltage E m cos omega o t and a DC side is V d.

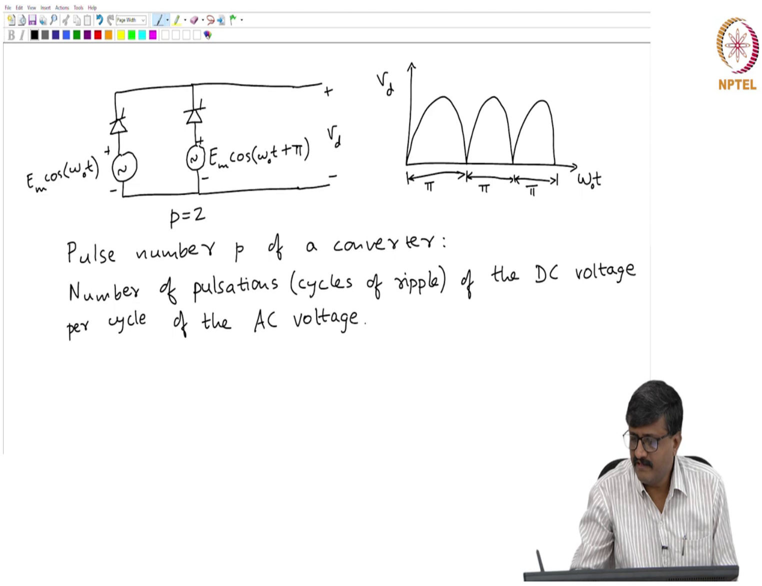
Now we are more familiar with a DC voltage which is constant, as a function of time. Now for the purpose of this course a DC voltage is a voltage whose average value is non zero. So, I will repeat a DC voltage is a average whose average value is non zero. So, when I say DC voltage or DC side voltage what I mean is an voltage with non zero average value.

Of course, AC side is a sinusoidal wave form so, average value is 0, ok. So, that is the definition of DC voltage that we will be following in this course the same thing is applicable in for the DC current. So, when is take the DC side current I mean it is not necessarily a constant value as time progresses, but it is something with which is of course, periodic and we will have a non zero average value ok, but if you look at this DC side voltage what will be the DC side voltage? It depends on the instant at which you turn on the device.

Suppose I turn on the device as if it is a diode; that means, suppose it a gate current which is always given continuously then it opt the thyristor acts as a diode. So, what will be the wave form? So, if I try to plot the instantaneous DC side voltage V d as a function of time, then I will not try to mark the values on the abscissa. If I just look at the waveform to assuming that there is a resistor across the DC side terminals for simplicity, it will have a waveform which is sinusoidal for one half cycle and 0 for the other half cycle and again sinusoidal.

So, what I get is a DC voltage, but it is nowhere close to what is desirable. Now what is desirable is the one that I have shown above I, I mean I need a constant DC voltage, but I will not able to get the constant voltage, but I should make it as close to the desired value as possible. So, how to alter this circuit of the converter in order to get a better DC side voltage. So, what we do is let me try to get to a slightly different circuit which gives us slightly better waveform.

(Refer Slide Time: 05:03)



Suppose I take instead of one thyristor I take two thyristors and of course, two voltage sources. So, let me call this instantaneous voltage across this voltage source as E m cos omega o t. Suppose this is E m cos omega o t plus a certain phase angle I will talk about this phase angle shortly. Now let me call this voltage across these two terminals as V d which is our DC side voltage.

Now the question is what should be this phi, what should be this phi, what is an obvious choice for phi? Suppose this first voltage is E m cos omega o t, what is the obvious choice for second voltage that I have here. So, it should be shifted by 180 degrees. Now my intention is I should get some symmetry in DC side voltage. So, if phi is pi so instead of phi if I make it say pi that is 180 degrees.

And if I give say for example, for this just for the sake of simplifying our analysis. So, assume that the gate current is constantly given. Then I get a waveform which is sinusoidal 0, say pi, I will try to try to not mark this one. So, what I am trying to say is each of these durations or of pi radian. So, this is pi radian, this is pi radian, this is pi radian. So, here the abscissa is omega o t. So, what I plotted here is V. Now compare this V d with the previous V d. So, the previous V d was something like this.

So, which is better I, mean without any mathematical analysis which appears to be better by just looking at the wave form. The one with, the one with two thyristors instead of one thyristor. Now there is some way of mathematically showing that one is better than the other one can try to find out what is the harmonic content. See what is desired is only DC the rest are harmonic components. So, one can show that the harmonic components compared to the DC is much smaller in the second circuit compared with what is there in the first circuit, ok.

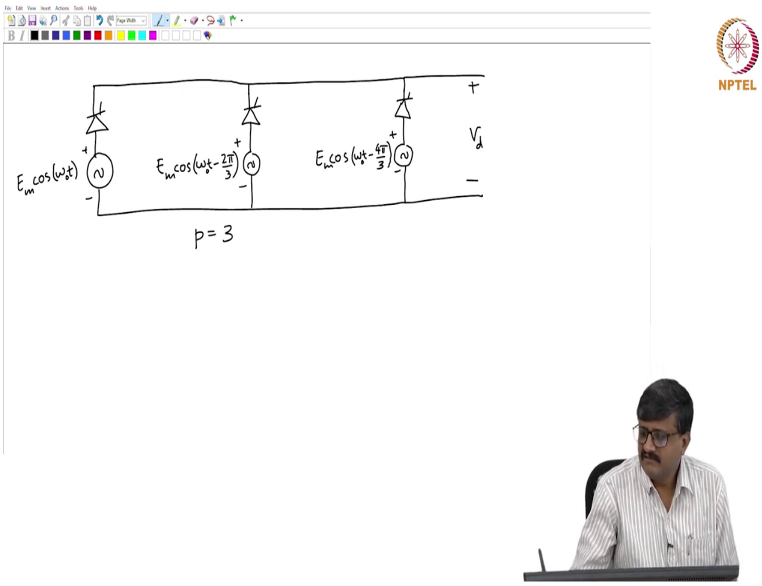
Now, can we further improve upon this? Say, what is our goal? Our goal is to get a constant DC, if that is not possible atleast get close to a constant DC voltage. Now why we started with simplest wave form. Now this is the most obvious circuit see we started with simple circuit of one voltage source and one thyristor we, because, because it is a most obvious one, ok. The next obvious circuit is adding one more sub circuit in parallel. So, if I want to improve upon this what one can do is I can try to add many such circuits in parallel.

So, the intension is to get close to a constant DC voltage, but you will never get a constant DC voltage, we will only get close to that. So, we will see what are known as pulsations. So, you will see that there are pulsations in the DC side voltage. So, if you look at this there are two pulsations per one cycle of the DC side voltage, ok. So, we will define what is known as a pulse number.

So, pulse number which is denoted by lower case p. So, this pulse number is defined for a converter. So, pulse number of a converter is defined as number of pulsations number of pulsations cycles or cycles of ripple. So, presume you are familiar with the. So, pulsations ripple the number of ripples that we get.

So, it is a number of pulsations of the DC voltage per cycle of the AC voltage. So, we see that in this case the pulse number happens to be two, because if you look at one cycle of the AC voltage. There are two pulsations of the DC voltage. So, this corresponds to p equal to 2. So, we can improve upon this see the next, let me just go to a slightly complicated circuit.

(Refer Slide Time: 11:07)



Suppose I want to further improve what I do is I take three voltage sources and three thyristors. Connect each such circuit like this. So, there a negative circuit there is thyristor in series with voltage source. So, there are three such circuits connected in parallel. Let the instantaneous voltage here the E m cos omega o t. Now these two voltages will have the same peak value, but different phase angle.

Now I mean I did not get into how to get the phase angle in the previous case, I get the phase angle is 180 degrees with respect to the previous voltage. Now that is something based on your experience in an undergraduate course may be in a power electronic course are able to say that. So, similarly I presume you should be able to say what should be the phase angle of this second voltage source. So, I can actually say that this should be shifted with respect to the first voltage source by?

Student: Pi by 2.

Pi by 2.

Student: 3 pi by 2.

3 pi by 2.

Student: 2 pi by 3.

2 pi by 3, so, if you may be a the previous circuit may give some hint pi by 2, 120, here the difference is only difference is 180 difference is 180.

Student: (Refer Time: 13:10).

Now, how did we get that 180, it is 360 divided by the number of such circuits in parallel. So, it is a plus 180 here. say plus 180 or minus 180 one and the same say even if I am make it minus 5 it is 1 and the same right both are one and the same, ok. So, here the phase shift should be 360 divided by number of such circuits is 3. So, it is 120. So, it should be minus 2 pi by 3 and this one should be E m cos omega o t say I have written minus 2 pi by 3 here, what should be; what should be written here minus

Student: 4 pi by 3.

4 pi by 3. So, in this case what is the pulse number 3. So, the pulse number as I said is defined as the number of pulsations of the DC voltage in one cycle of the AC voltage. Now it is also the number of pulses that are in total given to the entire circuit for an thyristors. See, if there is only one thyristor, I give only one pulse per cycle, ok, because there is only one thyristor. If there are two thyristors, there are two pulses to the two thyristors. Similarly, if there are three thyristors, there are three pulses negative pulses I am talking about, I am talking about the gate pulses that are.

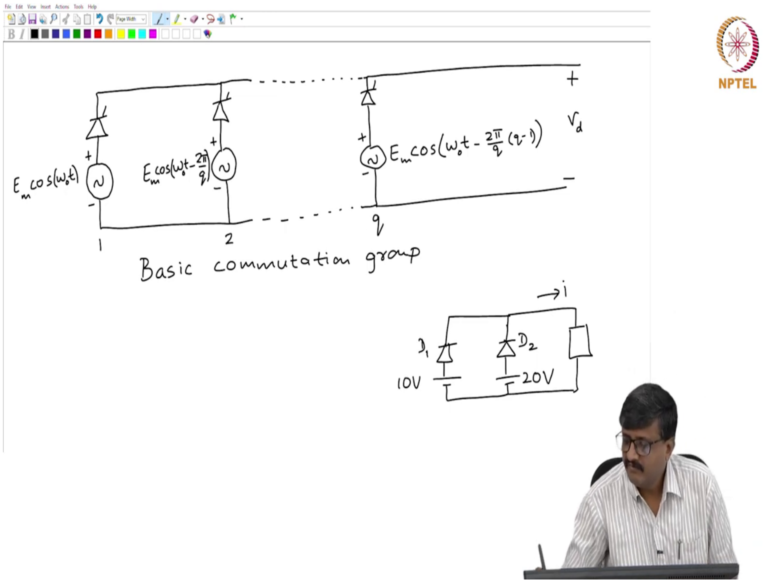
So, each thyristor is assumed to be turned on only once, another point is to be noted. See, these waveforms which are drawn the waveform of V d as the function of omega o t is assuming that the gate currents are continuously given. Now the purpose of having a thyristor is to get some control. I presume you are all familiar with the idea of changing the average value of V d by changing the instant at which the thyristor is turned on.

So, that is the idea. So, though I have drawn the wave form for the simplest case of continuous gate current. By changing the instant of gate pulse one can get a different V d which has the different average value of V d infact, ok. So, what we will try to do is we will try to see how this can be generalized. So, in general we can infact, say that there are many number of such circuits in parallel.

So, what is the idea? The idea is very simple start with the most obvious circuit and see how to improve this circuit in order to a DC side voltage which is close to the desired a waveform that is a constant value, ok. So, for that you added one similar circuit in parallel. In fact, identical circuit and in this case we have three such circuits in parallel. So, the DC side voltage is V d which is the voltage across these two terminals.

Now what I am going to show is instead of saying p is equal to 2 or p is equal to 3 and p is equal to 4 and so on I will just draw a very general circuit where I have q such circles in parallel. So, simple let me try to show a very general circuit now.

(Refer Slide Time: 16:35)



So, the voltage here is E m cos omega o t. So, I will come to this voltage, but what I am showing now is a very general circuit where suppose this is the first circuit consisting of a voltage source on a thyristor, this is the second circuit consisting of a voltage source and the thyristor and so on. Upto the last circuit which is the q th circuit say I denote the first two integer which corresponds to a number of such circuits this as q, ok.

So, for a general number of such identical circuits except for the phase shift, say they are the identical except for the phase shift of the voltage, ok. The peak value of the voltages are same. So, the peak value of the two voltage source shown here other than the first one is also here. So, what is the expression for the voltage across the second voltage source? Of course, it has a peak value E m cos omega o t minus what is the phase angle.

Student: 2 pi by q.

2 pi by q, ok. Now coming to the last one, the last voltage source that is the qth and not showing the third forth and so on, ok. So, q is some positive integer. So, this is E m cos omega o t minus what is the phase angle.

Student: (Refer Time: 19:00).

2 pi by q into q minus 1, right. So, if I take out these two terminals, these are the positive and negative terminals of the DC side the voltage across the DC side is V d. Now, the question is if you take a circuit like this at any instant how many thyristors conduct? Now for the sake of simplifying the analysis suppose, I assume that all these thyristors act as diode see if I give continuous gate current, ok.

So, assume that for the time being, assume that these are acting as diodes. If I give constraints see if I give thyristor is nothing, but a diode if I give a constant gate current suppose for the sake of simplifying the analysis I do that. How many thyristors are conducting at any instant, only one is that is I mean is that obvious, is that obvious or not, yes or no?

Student: Yes.

Yes some people are saying no.

Student: (Refer Time: 20:22).

It is obvious, if it is not let me know. Say, it is very easy to understand. Suppose I have 2 diodes, suppose I have 10 volts, 20 volts. So, this is a diode D 1, this is diode D 2. So, which diode conducts?

Student: D 2.

Now, of course, it is very difficult to say from this circuits, you should also show the DC sites. Suppose, there is a current flow possible here I connect something on the DC side, ok. So, if I connect something on the DC side and if some current I mean of course, both are DC sites for the sake of simplicity I quit instead of AC DC voltages. Suppose I connect something across these two terminals, ok. Some load is connected here say a resistor, ok. So, if some current flows here I then whether D 1 conducts or D 2 conducts or both conducts or none of D 2 conducts.

D 2 conducts, because both diodes are at I mean the cathodes of both diodes are at the same potential where as the anode of D 2 is at higher potential. So, it is forward biased. So, once D 2 conducts the diode D 1 is actually reverse biased. So, the potential of the anode with respect to cathode of D 1 is minus 10 volts. So, it is a negative voltage which is appearing across D 1, because D 2 is conducting. So, that is why D 1 conducts, sorry D 2 conducts.

So, similarly one can try to explain for the case of multiple circuits which are connected in parallel. So, that is what is happening in the case which has shown above. So, there are q circuits. So, the voltages are actually variables are sinusoidal, ok. So, the at any instant the thyristor whose anode is at the highest potential conducts all the cathodes are same potential, ok. So, assuming that I have continuous gate current, I can I mean for the sake of simplicity I can take diode operation by giving the gate current.

So, the point is at any instant only one thyristor conducts, ok. So, we give a name for this particular circuit, this circuit which has q such combinations of a thyristor and voltage. So, we call this as basic commutation group, these just a name basic commutation group. So, the idea is try to get a or build a circuit which has a waveform on the DC side close to the desired waveform that is a constant value, ok.

So, what we do is we try to connect such basic commutation groups many such basic commutation groups in parallel and series. So, suppose I take many such basic commutation groups in series and many such series combinations in parallel, I get a very general quarter.

So, that is how we build the converter. So, the intension is to actually get a waveform close to the DC side by having a very large value of what is known as pulse number.

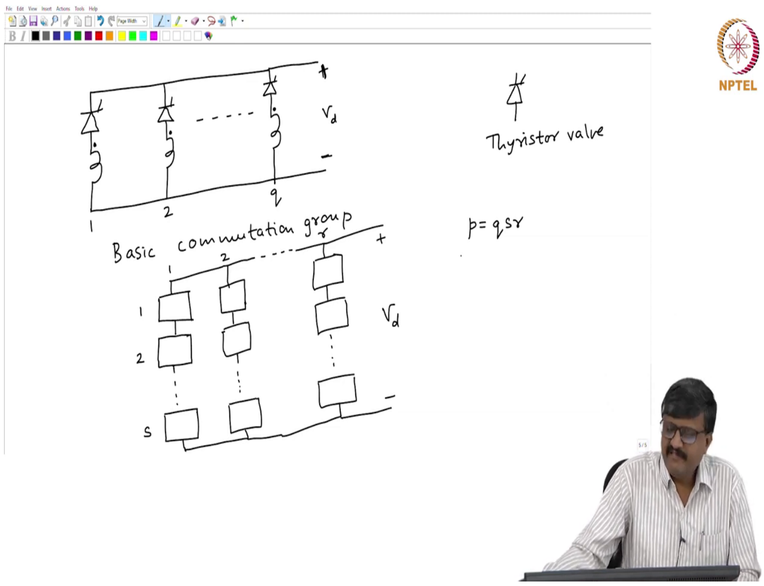
Now I am not, I am not using the same notation which I used earlier. See p was the notation used for pulse number here I am using a notation q for the number of thyristors which are there in the basic commutation group. Now, I reserve the notion p for pulse number which is the total number of thyristors or the total number of voltage sources which are there.

So, if I have many such basic commutation groups in series and many such series combinations in parallel. So, the total number is actually the pulse number. Now the idea here is no two voltages will have the same phase angle that is the idea. So, I mean the purpose of having different phase angles is I want to reduce the pulsations say, I want to get a waveform which is close to DC.

So, if I have many such basic commutation groups in series and many such series combinations in parallel there are so many number of voltage sources. So, it is actually equal to q into number of such things in series into number of such things in parallel. So, there are so many voltage sources, each one is at a having a different phase angle. So, the total phase angle is obtained by the ratio of 360 degree divided by the pulse number, ok. So, the pulse number is nothing, but the total number of such voltage sources are thyristors that I have, ok.

So, that is the idea. So, now, in practice how do we get this voltage sources. So, I mean, though I have for the sake of a simplifying the explanation I have shown as voltage sources. In practice, we get voltage sources as induced E m fs across the transformer winding. So, the practical circuit is something like this.

(Refer Slide Time: 25:53)



I have a thyristor connected in series with a transformer winding. So, there are q such transformer windings. So, this is first winding, this is second winding, this is qth winding and here I have the DC side voltage V d. So, this is the circuit of basic commutation group. Now one point to notice that in the practical circuit of the converter that is used at the transmission level, we cannot just use one thyristor in a any of the circuits, what we do is we use a series of thyristors to get the required voltage ratings.

Of course, we do not need parallel connection for the sake of getting the current rating. Say, in the last class mentioned that there was a time when we had to connect many thyristor devices, individual thyristor devices in parallel to get the current rating and many such connections in series to get the required voltage rating.

Now, the current rating is actually available. So, we have thyristors for the required current rating, but we do not have thyristors of the required voltage rating. So, when we connect many thyristor devices in series to get the required voltage rating, I will not show the individual devices. So, I will still use the same symbol.

See, if I use the symbol which is for the thyristor individual thyristor device I will still use this even for the series connection of many such things. So, if I mean, so, I gave a I mean I mentioned about this term thyristor valve. So, even for the thyristor valve I use the same symbol which is used for thyristor device, ok. So, I will not be showing multiple thyristors in series to show a thyristor valve, I just again use the same symbol.

So, in all the circuits are drawn the symbols actually mean thyristor valves, though it is I mean, it is the same symbol as that of the individual thyristor device, ok. So, what I will do is try to build a very general circuit. So, from the basic commutation group, I get a very general circuit of the converter. So, I just represent one basic commutation group by a box. And I connect many such identical basic commutation groups except for the phase shift of the voltage in series.

So, this is having many such basic commutation groups connected in series say, connecting in series means the terminal just marked it as plus here is connected to the terminal mark minus of another commutation group. Similarly, the terminal group mark minus here is connected to the terminal mark plus of the next basic commutation groups, ok.

So, connecting in series actually means connecting in series at the DC side at the DC, say the DC side is very obvious here, ok. There are so, many AC sites, I mean the either so, many AC side there are so many AC voltages or so many AC side terminals, but the DC side I mean id unique I mean there are only two terminals corresponding DC side. So, connecting in series is essentially means connecting in series on the DC side. So, I get so many basic commutation groups connected in series.

Now, I take an identical series combination and connected in parallel with the previous one. So, I have shown two such series combinations of basic commutation groups. Now what I do is I take many such identical series combination except for the voltage phase shift and connect them in parallel. So, each box which I am showing here is a basic commutation group. So, there are q thyristors and q transformer windings in each of these boxes. And finally, I call these two terminals as the DC side terminals and the voltage across this is V d, ok.

So, what I am trying to say is in each series connection there are S number of basic commutation groups. So, there are basic commutation groups connected in series. Similarly, I have 1 2 and so on upto r such series combinations in parallel. So, I am using the notation S for the number of commutation groups connected in series and I am using the notation r for the number of such series combinations, ok. So, in each of these boxes of course, there are q thyristors, q transformer windings. So, the pulse number that we get p is the product of q s r.

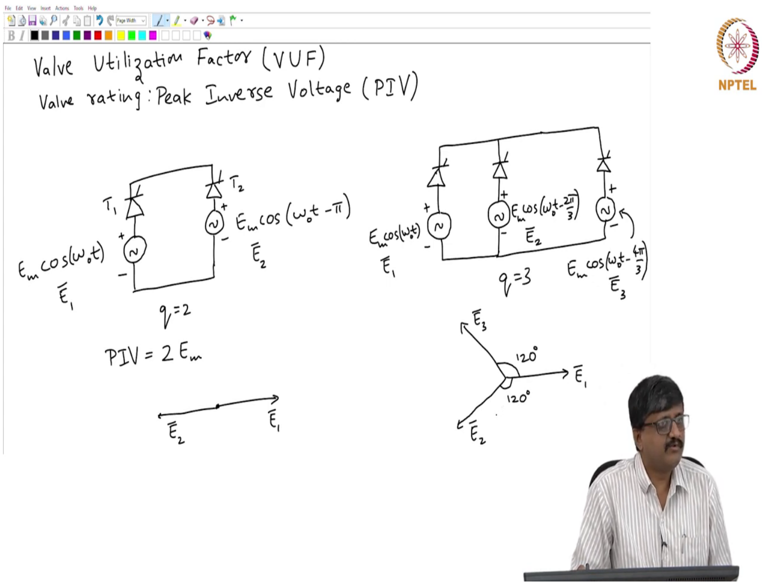
So, that so p is actually the total number of transformer windings, the total number of thyristors. So, what I am trying to say is we are we will get a very general converter circuit in this fashion. See, we started with a very simple circuit. And in the attempt to make the DC side voltage as close to the ideal waveform we arrived at this, ok.

Now, the question is how to choose the value of q value of r value of s is there any choice, I mean some values are better than others of course, the larger value is good, but for a given value of p for a given value of p are there some values of q r and s which are better than other. Since someway, so, that is what one has to do. So, what we will try to do now is do the selection of q r and s for a given value of p and infact in the process we will also select p I mean we will also give get some restrictions on p.

So, for that purpose we define some figure of merit see this figure of merit is something which will help us in arriving at the values of q s r and p as well, ok. So, let me move on to two figures of merit that will be defined. Now, it will help us in deciding the values of q r s. So, you can note down that I mean r is the number of parallel pairs and of course, s is the number of basic commutation groups connected in series, ok that is the notation s and r are just a notations for these quantities.

Now in any circuit what we expect is there is I mean maximum utilization. We want the utilization to be maximum. Say, if we use a component and if it is not utilized then we unnecessarily investing. So, what helps us in deciding these values or the utilization. So, are the utilization figures of merit will help us in deciding these values.

(Refer Slide Time: 34:27)



So, we actually define two utilization factors. So, the first utilization factor is the valve utilization factor abbreviated as VUF. So, for this I need few more definitions I need one of the valve ratings see. So, I am using the valve without the say normally they full term is thyristor valve. So, as I said thyristor valve is nothing, but a series combination of individual thyristor devices.

So, one of the valve ratings is the peak inverse voltage see, the peak inverse voltage is the one which actually appears. So, voltage of the cathode with respect to the anode. The peak inverse voltage, PIV. Now, if you look at basic commutation group, let me go back to the basic commutation group. So, I mean this particular figure also says what is the expression for the individual voltage sources.

So, what is the peak inverse voltage, you should take any thyristor, all thyristors are subjected of course, to the same peak inverse voltage, because all the voltages are having a peak value E m same voltage and there is, uniform phase shift between the voltage sources. So, what is the peak value of the voltage that appears across any thyristor.

Student: (Refer Time: 0:36:23).

E m.

Student: 2 E m.

2 E m, any other answer E m is 1 2 E m, its bit difficult to answer. Let us take some example say in order to solve the problem better to I mean if which is difficult go from special case to the general case I mean trying to direct solve a general case may be a bit of, ok. Let me take the simplest special case is two voltage sources again I am going back to the voltage source for a sake of explanation in practice itself transformer 1 D.

So, suppose I have a thyristor and a voltage source and another thyristor voltage source. This is just a special case where q is equal to 2. So, this is a special case of q equal to 2. So, in this case, it is E m cos omega o t and this is E m cos omega o t minus pi. Now what is the maximum possible voltage that can appear across the thyristor.

See at any instant one of the thyristors is conducting suppose let me call this as t 1 suppose this is t 2 see the voltage across the thyristor is not a constant I mean because the voltages which are appearing here are sinusoidal. So, the maximum voltage that appears across any of these thyristors when other thyristors conducting is.

Student: 2 E m.

2 E m, it is 2 E m. So, here peak inverse voltage is very obvious to 2 E m, but this is the just answer for q equal to 2, this is the answer for q equal to 2. Now suppose, I take the next complicated case slightly complicated case is q is equal to say 3. So, the voltage here is E m cos omega o t minus 4 pi by 3, this is voltage of course,. Now what do you say at any instant one of the thyristors is conducting is less than.

Student: 2 E m.

Less than 2 E m do you see that it is not 2 E m. See, if I try to draw the phasers in this case if one phaser in the case of q equal to 2 is like this suppose I take this as the phaser E 1. So, I show a bar that indicates a I show this phaser as E 2. So, if this is E 1 E 2 is out of phase or at a phase angle of 180 degrees with respect to E 1. Similarly, if I try to represent these voltages by phasers say E 1, E 2, E 3, ok.

So, if this is E 1 this is E 2 then this is E 3. So, the angle between any two phasers is 120 degrees. So, this is 120 degrees, these 120 degrees. Now, the peak value of the voltage between see what appears across thyristor is nothing, but the difference between any of these two voltages say, we are talking about the peak inverse voltage across the thyristor it is nothing, but the difference between any two voltages.

So, if you look at the case of q equal to 3, the difference between any two voltages they does not have a maximum value 2 E m it is less than 2 E m, ok. So, take the difference of the any two phasers E 1 E 2, E 2 E 3 or E 1 E 3. So, it is less than 2 M.