DC Power Transmission Systems
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Lecture - 06
Choice of converter configuration: Value utilization factor

So, in the last class we saw that the pulse number p can be written as the product of.

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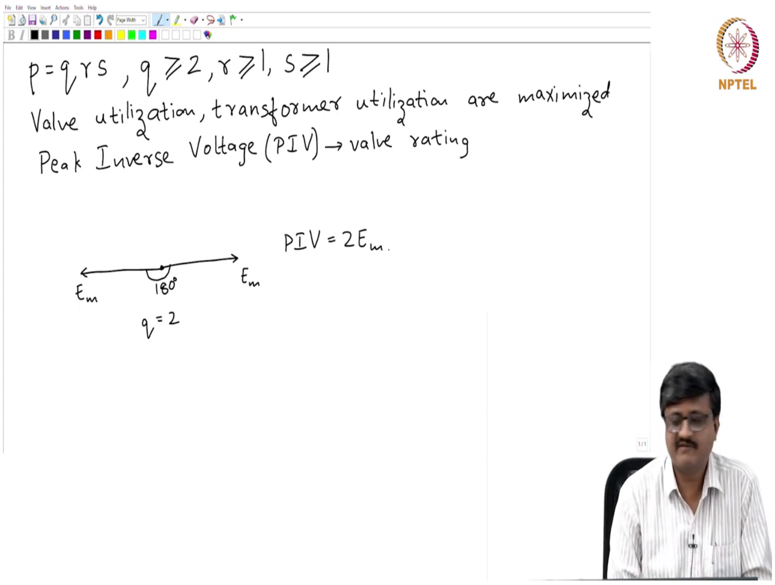

So, the pulse number p can be written as the product of three numbers q r s; q is the number of voltage sources or transformer windings or thyristors in a basic computation group, s number of basic computation groups in connected in series and such combinations there are r in number. So, totally we get a pulse number p equal to q r s. So, we started with q equal to 1; now that was for just for the sake of; telling you that that is the most obvious circuit.

Now, if you go from q equal to 1 to q equal to 2; there is a drastic improvement. So, we will consider only cases where q is greater than or equal to 2. So, here q is greater than or equal to 2, r is any positive integer, s is any positive integer. So, we have q r s as positive integers; the only constraint on q is we will consider only value is greater than or equal to 2, not 1. So, we have to somehow find the values of q r and s for a given value of p.

So, what we do is we try to see how the components are utilized. So, we will see that there is a valve; that is a thyristor valve we want to ensure that the utilization of the valve is maximized. So, we will try to maximize the utilization of the valve and there is a transformer; see the voltage source shown in the figure as actually the EMF across the transformer. So, we want to also see that the transformer utilization is maximized.

So, both these quantities are maximized. So, what we will try to do is; to arrive at some figure of merit which will ensure that transformer and valves are best utilized, we need some definitions. So, one of the definitions that we use is Peak Inverse Voltage; PIV. So, this actually a valve rating; so there is one of the valve rating. So, a valve will have many ratings. So, when I say rating; rating is something which is always giving the maximum possible value ok.

So, if I want to know what is a peak inverse voltage; so I have to consider different values of q that is what we were doing in the last class. So, if I take q equal to 2; then there are only two voltages. Now for the sake of simplicity what I will do is I will show these phasors with an arrow having a length proportional to the maximum value; instead of the usual RMS value; I mean this will help us in easily getting the expressions for peak inverse voltage.

So, if I have q equal to 2; then there are two voltages which are outer phase that is the angle between these two is 180 degrees. So, in this case the peak inverse voltage is 2 E m. So, if at any instant one of the thyristor is conducting; then the voltage across the other thyristor will be subjected to a peak value of two times E m ok; so the that is very straight forward in the case of q equal to 2.

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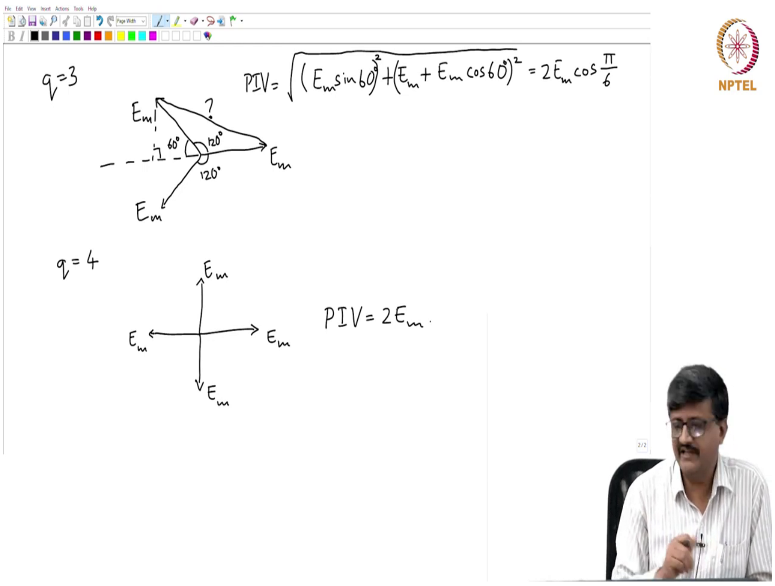

Now, let us go to q equal to say 3. So I can again draw the phasor diagram; so there are three phasors E m is a peak value and the angle between any two of these three phasors is 120 degrees. Now, there are no two voltages which are outer phase; I mean the phase angle is at most, the phase angle differences at most 120.

So, if I take the maximum value of the difference between any two voltages; I will get the peak inverse voltage. So, if I try to take any two voltages and try to find the maximum. So, the length of the line which is joining this end of the; arrow on this end of this arrow will give me the peak inverse voltage. So, I can try to find this; suppose I extend this line, I will extent drop a perpendicular here.

So, this angle is 60 degrees; so the peak value in question is this one. So, I want to find the length of this line segment. So, what is the length of this line segment in terms of E m? So, I have to just take a one length which E m sin 60 and the other length is E m plus E m cos 60; so this is one length, there is another length. So, I just take the square of these two lengths and take the square root. So, this is the peak inverse voltage; so we can simplify this.

So, one can show that this is equal to 2 times E m cos. So, it can; say what I am trying to do is I am trying to finally, get it in terms of q that is what. So, I have taken a special case of q here q is equal to 3. So here q is equal to 3; so this is a pi by 6; so this can be easily verified.

So, though I have written initially the angle in terms of a degree pi by 6 is in radians ok; so this can be easily verified. Now, let me just take one more special case before going to the general case. So, if I have q equal to 4; then if I try to draw the phasor diagram, I get four phasors all having a peak value E m.

So in this case, if I want the peak inverse voltage; you just take a any two phasors which are outer phase. So, PIV is 2 E m; so this was the answer we obtain even for q equal to 2. Now, it so happens that for any even value of q; we get the peak inverse voltage as 2 E m because there I can always find two phasors which are outer phase or having a phase angle difference of 180 degrees; now how to do for a general odd value?

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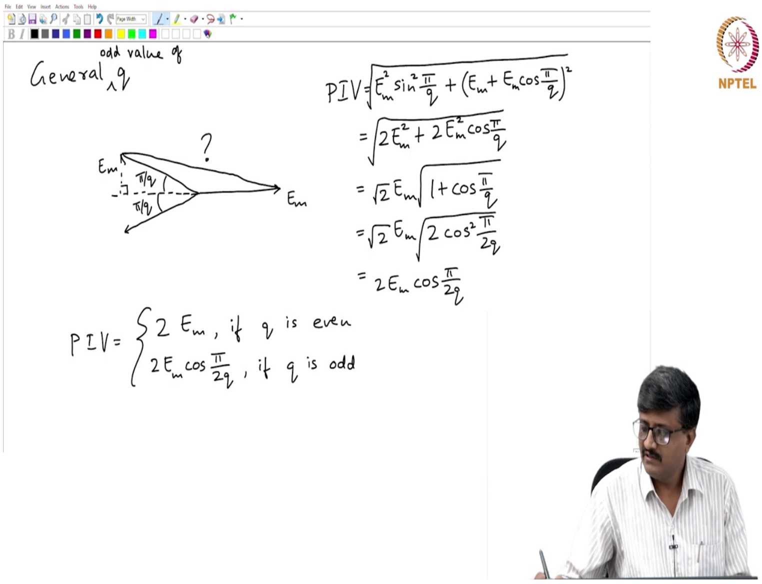

Take any general q; now what I am interested is though there are q waveforms; I am only interested in any two wave forms such that I get a peak inverse voltage. So, I have to take two phasors which are displaced; which are having the maximum displacement between them. So, if I try to just show, the two phasors which will give me the maximum displacement then, there will not be displaced by 180 degrees. Now, what I will do? I will just extend this a straight line along which one of the phasors is located by a dashed line.

Now, my interest is the difference between these two phasors. So, if I have properly selected the two phasors; what is the angle that I have shown here?

Student: Pi by q.

Pi by?

Student: q.

q; so how is its pi by q?

Student: (Refer Time: 09:23) because next phasor after (Refer Time: 09:24).

Yeah. So, between any two adjacent phasors the angle is?

Student: 2 pi by q.

2 pi by q. So, between any two adjacent phasors is 2 pi by q. So, that is why the other phasor which is coming next to this is having an angle of 2 pi by q. So, the angle between these two is 2 pi by q so, but I need this pi by q because I need to find this length. So, what I am interested is in this length; what is this length. So, this is similar to the case of a q equal to 3. So, only the in the case of q equal to 3; we have instead of pi by q we had 60 degrees. So, we have a general value for the angle here pi by q.

So, in this case PIV is equal to. So, if I take a line segment which is perpendicular to the other line segment; then I can use this right angle triangle to find pi. So, what I have here is one side of the right angle triangle is E m sin pi by q. So, I will take a square of this and add it to the square of the other side length of the right angle triangle; that is E m plus E m cos pi by q whole square and take the square root. So, this can be simplified; so there is E m square sin square pi by q and E m square cos square pi by q and E m square as well.

So, there is an E m square appearing twic; so 2 E m square plus 2 E m. So, it is this E; so 2 E m square cos pi by q under root ok. So, let me take the common factor outside; root 2 E m under root 1 plus cos pi by q. So, in other words; this is a root 2; root 2 E m. So, this can be written as 2 times cos square pi by 2 q. So, finally I get the expression as 2 E m cos pi by 2 q.

So, PIV is either equal to 2 E m, if q is even or it is 2 E m cos pi by 2 q; if q is odd. So, this is one of the valve ratings; peak inverse voltage is one of the valve ratings.

So, we will see how to use this to get some measure of the utilization, but before going to the measure of utilization, we need one more quantity that is known as the maximum average DC voltage. So, if this is clear; let me move on to the next yeah, if at all you want to go to the previous page you have to just to prompt me; so that I can go yeah. So, as soon as something is over I will go to the next page. So, please prompt me if you want me to go back to the previous picture. So, this is PIV; I will be using this for getting one of the figures of merit.

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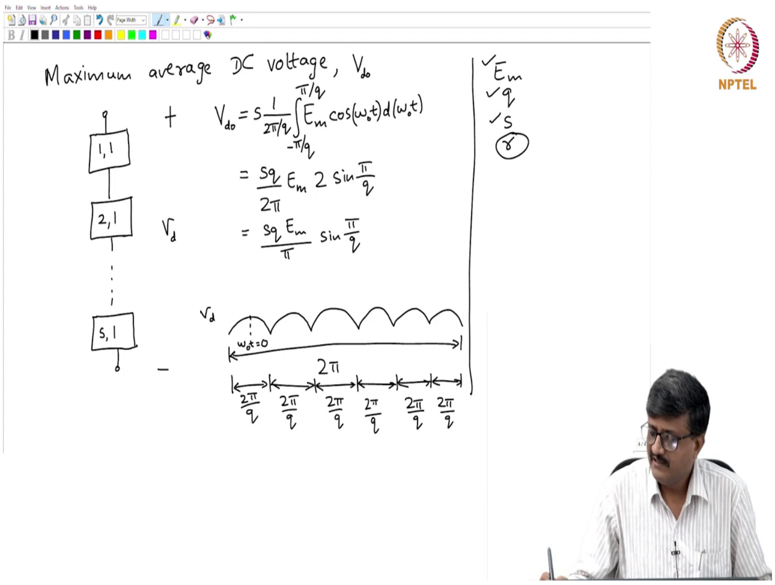

So, before going to the actual figure of merit; I will design one I mean I will define one more quantity that is a maximum average DC voltage. So, we have a notation for this, I will use the notation uppercase V with two subscripts do. So, V do is the notation for maximum average

DC voltage. Now, why the objective maximum is coming here? So, we are using a thyristor depending on the firing angle of the thyristor; we get different average DC voltages ok. Now, when do we get maximum?

Student: (Refer Time: 14:14).

So, when.

Student: (Refer Time: 14:18)

When the thyristor acts as a diode.

Student: Diode.

As if it is a diode; that means, if I give continuous gate current as if the thyristor, then the thyristor behaves as if it is a diode so, then I get an average DC voltage. So, how do I get the expression for the maximum average DC voltage in terms of the other quantities which are known? So, we have a AC voltage in terms of E m and we have a basic computation group in which there are q thyristors or q voltage sources. And there is a I mean a set of basic commutation groups connected in series. So, s number of basic commutation groups connected in series, r number of such series connections connected in parallel.

So, can we get the maximum average DC voltage in terms of these quantities? First of all we have let me just note down what we have the quantities that we have; in the voltage we have E m, we have q as the number of a thyristors in a basic commutation group, we have s as the number of basic commutation groups connected in series and we have r as the number of such series connections connected in parallel. Now, does the maximum average DC voltage depend on all these four quantities?

Student: No.

No.

Student: It will depend upon the parallel path.

Yeah, it is irrespective of the number of parallel paths ok. So, it will not depend on r. So, it depends on now it appears it depends on E m q on this. So, can I get an expression? So, what I need to do is I just need to take only one of the parallel paths and use it to find the average DC voltage; all these are connected in parallel. So, the voltage across all these parallel paths is one and the same ok. So, I mean I take can take any arbitrary parallel path and try to find the voltage. So, what I need to do is; I need to take the voltage across each and every basic commutation group and I have to add them to get the effective voltage.

Now, there is one simplification possible here; should I take each and every possible. I mean basic commutation group that is connected in series? Should I take each and every basic commutation group connected in series; find the average see the point is ok, let me show one path one parallel path ok. So, this box indicates a I mean a basic commutation group. So, there are s such basic commutation groups connected in series ok.

So, the voltage that appears between this terminal and this terminal is v d; see the lower case v with a subscript d is the instantaneous DC voltage, where as what I am trying to find is the maximum average DC voltage ok.

So, I will give gave some name here 1 comma 1, 2 comma 1 and so on up to s comma 1. So, the first number is the number in the parallel in the path and the second number a is actually saying that it is the first path. The average across each of them; if added will give me the total average ok. So, should I find each and every average? There are s number of average values.

Student: So, average.

All averages are same?

Student: Yes (Refer Time: 17:46).

All averages are same. So, I can find any one average and multiplied by?

Student: s.

s ok. So, straight away let me get the expression for v do. So, it is s times the average across one basic commutation; now what is the expression for average for one of the basic commutation groups?

Student: If we number of dependent number of q and those many (Refer Time: 18:16).

Yeah, can I get the expression? How to get the average in terms of say it is a in terms of E m; E m and q, s is already s has already come here. Say please note s has already come; so I should write the remaining expression in terms of E m and q. So, we have an AC voltage source, we have an AC voltage source. So, what we are talking about is the maximum average DC voltage. So, if you look at the maximum average DC voltage; then we get that only if the thyristors operate as diodes; that means,. So, if I take one cycle of the AC side. So, I have shown here say q is equal to 6; suppose q is equal to 6 and this is one cycle.

So, one cycle means say 2 pi; now each of these widths each of these what is the length of each of these intervals.

Student: 2 pi by q.

2 pi by q. So, this is 2 pi by q; this is 2 pi by q and so on. Now, each of these widths has a part of a sinusoidal wave form. So, if you take any duration of width 2 pi by q; it is a sinusoidal waveform. Now, the peak value is appearing exactly at the midpoint of the interval 2; of width 2 pi by q, take any interval of width 2 pi by q; at the midpoint you get the peak at the midpoint, you get the peak ok.

So, it is part of a sinusoidal waveform whose midpoint is such that the peak is coinciding with that ok. So, the peak of the sinusoidal voltage which is appearing any width is having a peak value at the midpoint. Now, the question is if this is the case; this is the case for maximum say the waveform may be different, if I am not interested in maximum ok; I am only interested in the maximum average DC voltage. So, if this is the condition, how to get the average?

Student: (Refer Time: 20:40) degrade with the 0 to pi by q.

Yeah, yeah one point you notice that this is repeating after every 2 pi q radians. So, I need not integrate for 2 pi radians; I can just integrate for 2 pi by q radians ok. So, if I want the average just integrate for 2 pi by q radian. So, what is the expression to be integrated of course, it has to be integrated between two limits whose difference is 2 pi by q. So, I have to integrate what?

Student: E m sin theta.

E m sin theta.

Student: (Refer Time: 21:16) sin theta by.

Yeah, let us take the independent variable as omega o t; omega o t is the independent variable it is the angle ok. So, peak value is E m.

Student: (Refer Time: 21:33) plus.

Now, an easy way is say; I can arbitrarily fix the instant t equal to 0 or omega t omega o t equal to 0. Suppose I fix it here at the peak; suppose I call this corresponds to omega o t equal to 0; the instant at which peak occurs then what is this waveform? It is E m?

Student: (Refer Time: 22:06).

Cos omega ot ok. So, if I integrate this with respect omega o t between the limits; what will be the lower limit?

Student: (Refer Time: 22:22) minus pi by.

No, I want to integrate over a duration of 2 pi by q radian. So, if this is 0; I have to integrate from.

Student: Minus pi by q.

Minus pi by q to plus pi by q. So, minus pi by q to plus pi by q and I want the average value. So, I should divide this by?

Student: 2 pi by q.

2 pi by q. So, that is the expression for V do we can simplify this ok. So, what do we get if you simplify this?

Student: E m sin square (Refer Time: 23:00).

Sin square 1; if you integrate cos.

Student: Yes, I have integrated from sin like I have put omega will be 0 as this point.

irrespective of; I mean what waveform your I mean integrating where you fixed the omega t equal to 0; I mean you get a I mean it is the expression for V do is independent of where you fix t equal to 0 of course, ok. So, if you do that let me just give a some more steps. So, it is s q by 2 pi E m.

So, please note that we are integrating with respect to omega o t. So, this will be 2 into sin pi by q is that ok? So, just for one cancellation of 2 occurs. So, what we get is s q E m by pi; sin pi by q. So, this is the maximum average DC voltage. So, we have defined two quantities; one is the peak inverse voltage and the other one is the maximum average DC voltage.

So, if you look at the expression for V do; it depends on E m, it depends on q, it depends on s, but it is independent of r ok.

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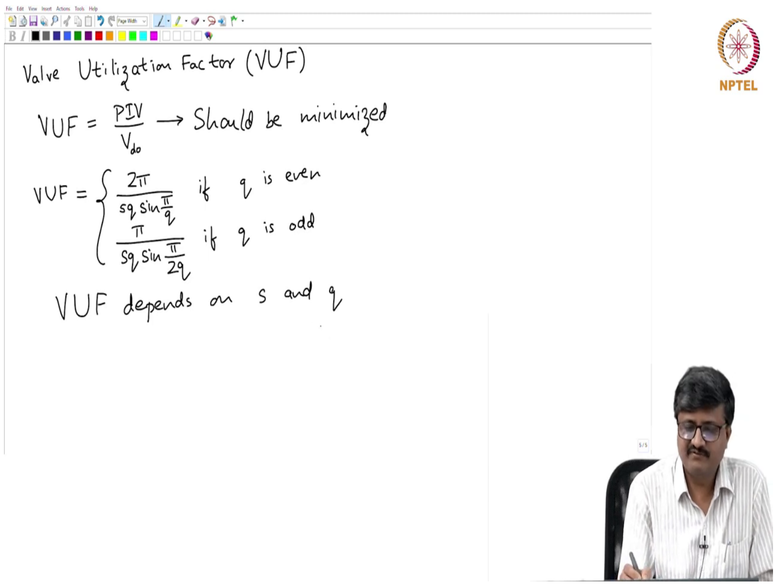

Now, we will come to the figure of merit which will help us in deciding the values of q, r and s for a given value of p. So, one figure of merit is known as Valve Utilization Factor abbreviated as VUF. So, the definition is the definition of VUF is; it is the ratio of PIV, the Peak Inverse Voltage to V do. Now, how does this make sense? Now, for a given value of a maximum average DC voltage; do I want a lower value of PIV or a higher value of PIV;

which is desirable? For a given V do what is desirable a lower PIV as lower value of PIV is possible as larger value?.

Student: (Refer Time: 25:37) large.

As large; say you take a large if you have, if you want a large PIV and you get a small V do are you utilizing the valve better? I will repeat the question for a given V do; suppose I fixed the maximum average DC voltage which is desirable? To have a large value of PIV or a small value of PIV? See, if I want a large value of PIV, I have to spend more. See, if I want a thyristor which has to withstand more voltage; then I have to spend more its more expensive ok. For a given V do; I always go for a case where PIV is low yeah.

There may be a slight chance of confusion here because we say that utilization should be maximized, but the factor which is defined here valve utilization factor should be actually minimized ok. I mean this is just because it is defined that way I mean the books that I refer to actually do this definition. So, I want I have to minimize VUF if I want to improve the utilization. So, it just it is slightly confusing; please note I want to increase the maximize the valve utilization so that is equivalent to minimizing value utilization factor. So, that is because of the definition of the valve utilization factor directly.

So, for a given V do I always want a PIV as low as possible. So, this should be minimized; should be minimized ok. So, let us try to get the expression for VUF by substituting the expressions for PIV and V do. So, we have one expression for V do, but for PIV we have two different expressions; so one for odd values of q, one for even values of q ok. So, if I want the expression for VUF I get 2.

So, let me first write the expression for q equal to an even integer. So, I will straight away write the expression you can just verify by looking at the expressions for PIV and V do; it is 2 pi by s q sin pi by q; if q is even is that ? So, just in the previous page we got the expression for V do and for q equal to an even integer; it is 2 E m. So, there is an E m in both expressions that gets cancel yeah.

So, what we get for VUF is this expression if q is even. So, if q is odd of course, here we need to substitute for PIV and V do and do a small manipulation or from which we get a pi by s q sin pi by 2 q; if q is odd is this ok? Yeah q equal to even it was just substitution; here just minor manipulation is required to get this. So, we see that VUF is dependent on q, it is dependent on s; it is not depending on r, it is also not depending on E m; it is independent of E m, it is independent of r.

So, VUF depends on or is a function of s and q. So, irrespective of whether q is even or odd it depends on s and q only fine. So, why I am trying to say that it depends on s and q is; our intention is to select values of q, r and s for a given value of p.

So, whether all choices are equally same or they are different. So, we make the choices in order to minimize VUF of course, this not the only figure of merit that we are looking at there is one more figure of merit. So, will try to say how these two figure soft merit; in fact, take the values for different values of q, r, s ok.