High Voltage DC Transmission

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Module No. # 02

Lecture No. # 02

Three-Phase Rectifier Circuits

Welcome to lecture number two of module two. In the lecture one of this module, I discussed about the single-phase rectifier circuit, and also I gave some introductory remark about the three-phase one way rectifier circuit.

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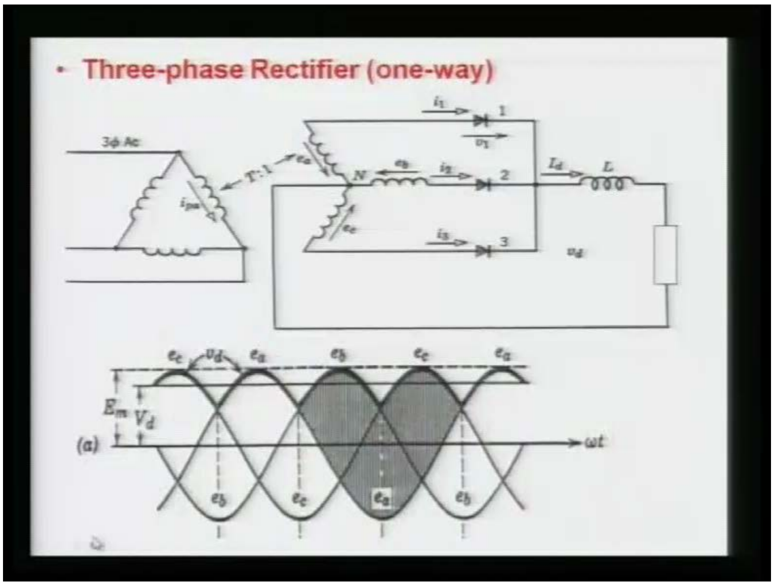

Here this circuit, I explained in the previous lecture, it was a three- phase one way circuit and here it is giving the three pulses. Now, I will generalize this concept, so that we can go for the six pulse and the twelve pulse rectifier circuit; the same figure was shown in your the previous lecture. And now I want to generalize, what will be the DC output voltage, and how we are going to calculate it? The DC output voltage, if you will see in this circuit, here it is the pulses; that is this is going to be this pulse; this is pulse and this is well, three pulses in one cycle so, it is a repetitive.

So, we can take the Everest of this even though e a phase is starting from e b to e b, e c here. That is nothing but over 120 degree. Now so, there are so many ways to calculate the DC output voltage as I explained even on the previous turn. Here one way that we can take the cosine and that is a very convenient. Now I will just show you, how the V DC is going to be calculated for this circuit. Now we can write the e a equation, taking this as a axis, if this is your axis where omega t is equal to zero.

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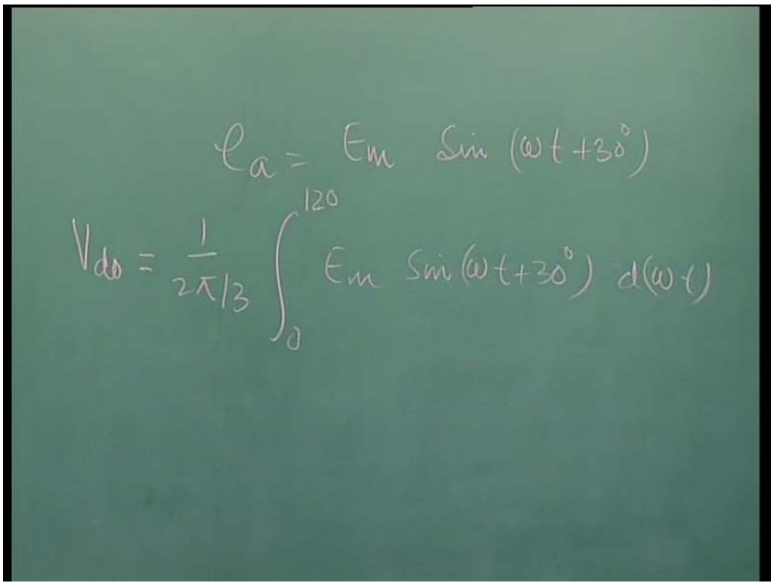

Now we can write this e a is… it is nothing but your e a here; it is your e m; E m it is your peak value of the phase voltage and then here I can write sine omega t plus thirty, because it is a 30 degree shift. You can see here, this is the going be e a going to be zero at this point means, this angle is your thirty degree.

Now to take the V d o here which we can define, now hold this pulse is for one twenty degree or I can say 2 pi by 3 and I have to integrate, integration we will see later. This is your E m sine omega t plus 30 degree and this will be the integrated with the d omega t. Now here, since we are taking our axis is starting, as I said here omega t is equal to zero means we are going to integrate here from 0 to 120 degree, because this one pulse and if you deriving this, you will get the same expressions which we derive the last turn.

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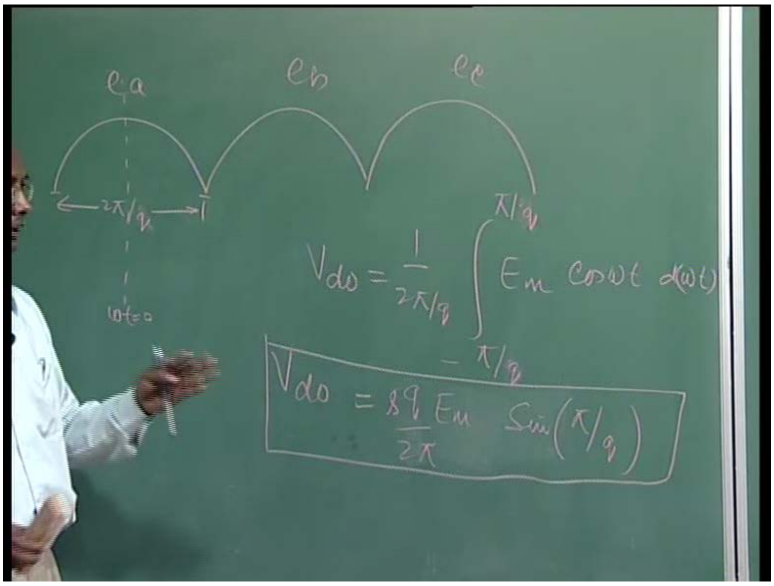

Another way here as I said and we will follow this equation, because once we will go for the complete converter analysis with the different modes of operation will always follow here. If you see this is your e a is coming; here it is your e b is coming, for this… this converter circuit, this is your e c.

It is possible that we can write a cosine equation; we can take a axis here means, our axis here I am writing omega t is equal to 0. And then, we can integrate from this to this, that will be again giving the DC output voltage means, here now I can write here V d o will be nothing but the total span here, taking as a cosine here. So, it is your 2 pi by 3 integration.

Now, this is your axis omega t is equal to zero means here and the total here it is your 2 pi by 3 means half of this is this side, half of this side. So, I can write here, it is your pi by 3 minus here your pi by 3 means 60, 60 degree; 60 this side; 60 this side. And now, I can write again here e m now, it is your cosine omega t d omega t. No doubt, there will be no difference in the value here as well as here; only here you can see, if you are going to integrate this, this becomes complex. Compared to this, this is the very simple, because the integration of this is simply it is your sine and this values are also very small. So, there will be no confusion.

But at the same time here, this output as I derived last turn also it was your twice pi. So, this representation or derivation of V d o is , very efficient and we will follow further later lecture, because we will see this wave shape will be not uniform all the time.

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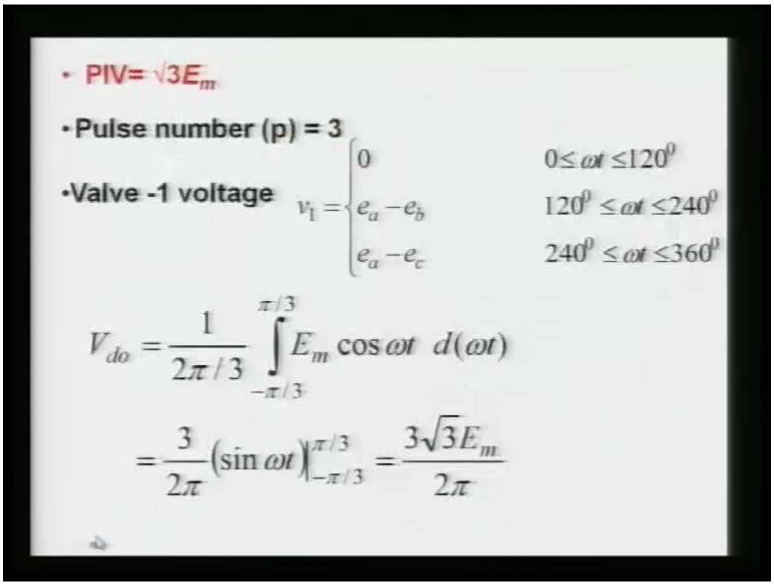

There will be so many here jumps will be arising, when we will go for the actual converter circuit with the different modes of operation. Moreover here in this whole analysis, we will now we are going to generalize, this is for the case when it is three pulses in one cycle. Later on, we will see the six pulses and also will see the twelve pulses. Then this value in terms of if you remember, I define this q here means I wrote this pulse number p is q r and s; p is your pulse number and q is a number of valve in a commutating group.

The group you have to form, it should be larger and should be symmetric and at same time, it should be large number of valve should be accommodated. Now this r is as I said is the parallel path and s is in series.

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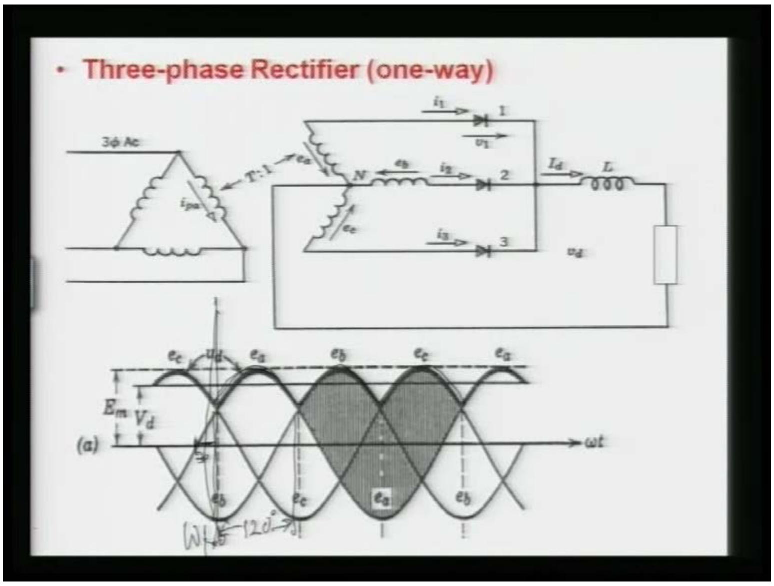

Now in this circuit which here in the circuit, now you can see what will be your q? The q here in this circuit; it is nothing but, we can form this is a as I said even though one valve can form one commutation group, because one is conducting at a time, but I said this is a large number of valves group here. Now we can form here, it is one group. So, it is q is equal to three. Your series valves are one, parallels are also one and then we are getting here is three is to one is to one; here we are getting three pulses. Now why I am defining here, because this expression itself I want to write in terms of p q r s values. So, that we can generalize and we will see in terms of p q r s, what should be the best suitable feature always will consideration of converter circuit? So, now here it will again in this expression which again I have defined here.

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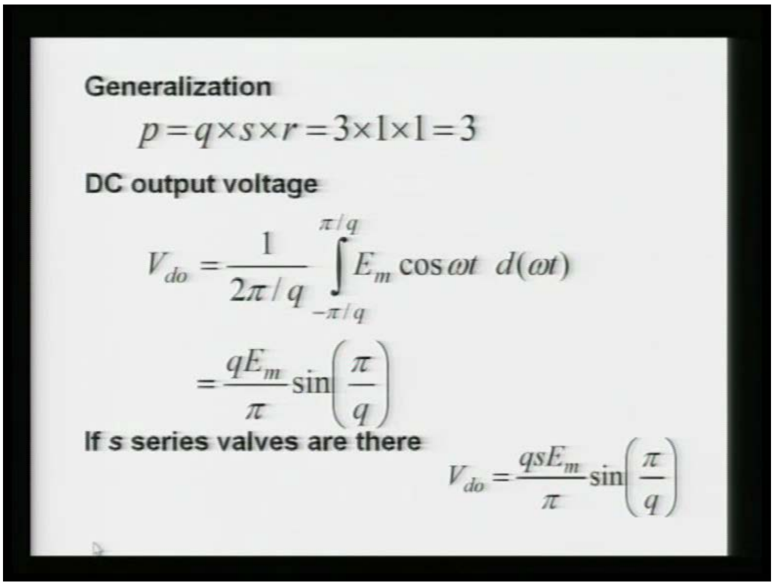

So your V d o, we can now you can see here; this q means is 3 in this case it is nothing but it is your, I can write in terms of q. This is your for all the circuit will find. This is the basically depends upon, how much duration it will conduct? It depends upon your q, because in whole this 360, the 3 here the pulses are arising. So, it is a 2 pi by q is arising here. Now here again, I can now write it is your q, here I can write the q, here I can write again q and then I have to write this expression. And if you will solve it here, what you are going to get? This expression will be changed now and we are going to get here; this is your q over twice pi E m.

Now, it is your sine pi over... So, you the DC output voltage can be expressed in general, in terms of your q; that is a commit number of valves in a commutation group. For this case, if you put the q is equal to 3, you will get the same expression. Now there is another term; here we will find. Here the number of this s that is unity; if the 2 valves are coming, the winding is coming the twice in a one path, the winding of that secondary of the transformer is means if the voltage is going to be added. And that is going to be added means, it is going to be that times of this. So, here this s will be appearing, if there is s number of series valve in that one commutation path.

So, your complete output voltage here without delay; again I just I want to remind here I am using. I am not delaying here is your thyristors are fired at instant omega t is equal to zero, means alpha delay is zero; alpha is angle which will be this simulator r.

So, your this V d o here, in terms of your q we got this value. This value will be used when we will go for the desired features of converter circuit, will be using this V d o all the time; In terms of s and q. Now another thing I will require here in this the valve voltage; valve voltage also required, because the valves we have to have the valves having the features even though there will be some problems in the mall operation of valve, depending upon what is the voltage appearing across this valve. So, for this example, for this circuit the valve here having the three-phases means, one it is a conducting so, it is 0; once it is in non- conduction, remaining period it is non-conducting.

So, the voltage is appearing in the different means, here for you again you can see the voltage wave shape as even though I explained last turn. Here in this circuit once one is conducting here; the voltage across is 0. Once this is going to conduct, and then the voltage here this e b is appearing here. And this is e a means, e a minus e b is appearing across this, once it is going to conduct here; then it is here, the e c is appearing and e m is e a minus e c. So, three different periods are coming here, but it is not limited to three. Here we are assuming that this valve, the current which was flowing here is directly instantaneously going to be taken by this valve two. But in the practical case, it will be not.

Because there will be sometime between commutation; that is called commutation period, because the current which is completely going from this to this. It will be taking some time, means there will be some instants; that is one and two will be also conducting. So, there will be another mode and other period, and then voltage will be the different across this.

So, we will find this voltage across this will be having the so many patterns and then we have to draw and we have to analyze. Because several times there will be possibility that due to reason though the short circuit are this 2 1 2 and 3 are conducting together, what will be the voltage here? It will be just like a short circuit here. So, the voltage here will be different and there will be some certain jump across this valve voltage.

So, for the mall operation analysis and the protection of the converter circuit, these things are very much required so, we will see later on. Here we are talking the ideal circuit right now, because we are assuming the current is, if valve one is conducting and we are the valve two is fired, then current is instantaneously taken care by valve two and that is why there is no two valve conduction mode. We will analyze later.

So in this here, I want to say that we have to very minutely see what will be the voltage across the valve? So, that we can draw the complete one cycle, the voltage profile seen by an individual valve and that will be 360 degree. So, in this case it is very simple; if once it is conducting so, 120 degree it is conducting. And we are assuming, our instant is omega t is equal to 0 when it is going to start valve one. Then e a minus e b for the remaining 20 degree and then e a minus e c will appear for very minimum 20 degree. So, this is a complete one cycle valve voltage is going to appear and then, we have to see the in later stages what will the various jumps in here and there.

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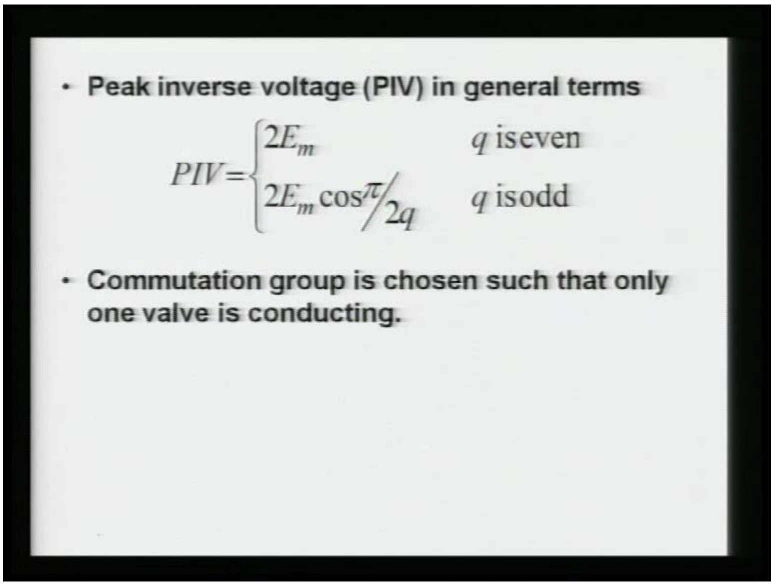

Now, another here the terms which we are going to use that is your peak inverse voltage and again, I am going to define the peak inverse voltage in terms of your q.

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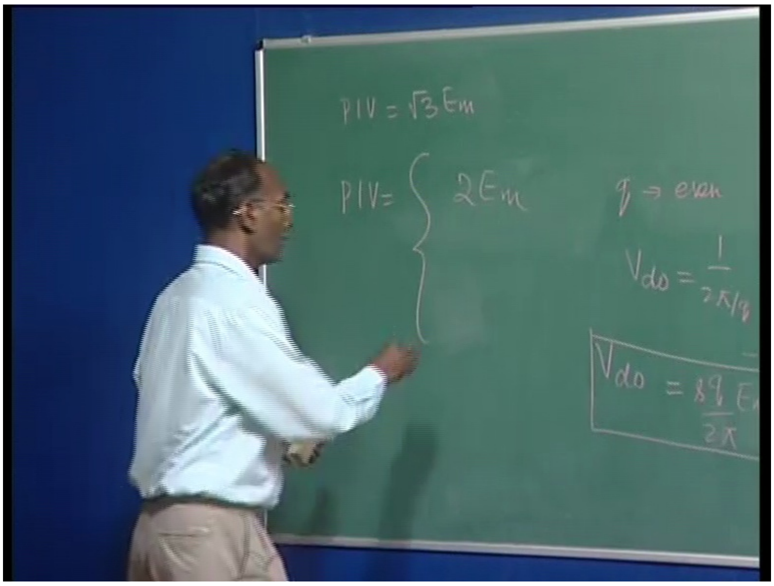

Already for this circuit, we saw that your PIV is nothing but you are under root 3 E m; it was found here for the different value of q means, q is only governing criteria to decide, what will be the peak inverse voltage across the valve. And this peak inverse voltage is very important, because the cost of valve is decided by this peak inverse voltage. If the peak inverse voltage is more, we have to go for a valve that can sustain that peak inverse voltage; otherwise this will be punctual. So, once the q is odd, here the q is three. So, if you put the q is equal to three, you will find that we are going to get. Here this value means, the PIV in general means we can generalize here it is your twice E m, if your q is even.

Just remember your circuit, when we were discussing the full wave rectifier; it was 2 E m, the peak inverse voltage. Because q at that time it was twice, because the 2 pulses were there r was one s was one. So, but the peak inverse voltage here it was 2 E m if you remember, then when we were analyzing that your full wave rectifier not the bridge circuit through full wave rectifier circuit.

For this q is here, once it is odd; it will be related by this expression and you can put here for this case q is 3, you will going to get this value here. So, this is the general expression for the peak inverse voltage which is basically depends upon the commutation number of valves in a commutating group; it is decided by two expressions. So, the decision of commutation group is very, very important. If you are not deciding commutation group properly, then there is a possibility that you are just landing with all this wrong expressions here.

So, the differential of the commutation groups which I gave in the beginning of this module that it is very important that you have to choose the number of valves. The group of the number of valves in a group which are conducting at a time and this is the maximum number of group of valves, it should be symmetrical. We will see again, when we will go for the bridge circuit and the circuits, then we will decide how we are considering all these

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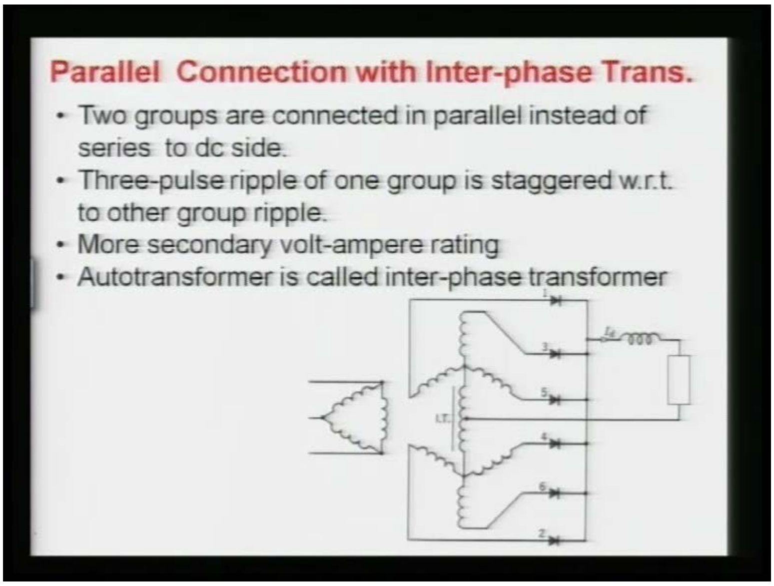

Now, let us some other six pulse converter circuits, it is a basically 6 pulse converter circuit. It is a even though first circuit which showed I to showed you today, it was the one way circuit it is called and we had the three pulses only.

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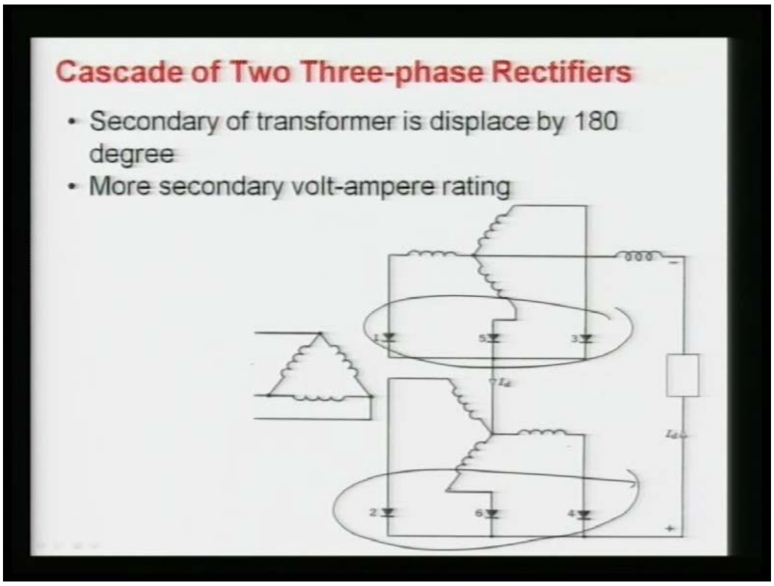

Now this that one way can be added in the two ways and see here. Here you can just see this portion the first half, it is a just similar just similar to our one way; only this was going as a neutral of this here. This is the three winding transformer is a just similar what we discussed just now.

There were three for the individual phases. Why it is shown in a just even a curve manner? Because this transformer this is your, if you imagining here it is A phase; now A phase are corresponding to secondary, it is A here. Similarly, if it is A phase, the corresponding secondary here is here in this transformer so, your transformer secondary having the two windings. And these two are basically displaced by 120 degree already here I have written. So, what happens the rating of this secondary bindings increases? So, your transformer size is going to be larger and you have to be manufacture in such a way that it should be here that amount of voltage as well as the current in the secondary side. Now this as I said here you can see, what will be your commutation group here? For having a complete path here, we should have at least one valve here in the lower portion and valve here; then we can have complete circuit. So, the commutation here, you will see the three valves. Even we can have two commutation groups having the three valves each means, we are having here one group here and we can form one group here.

And in this case, we are having the s is equal to two, because here the three valves means in this commutation group; here over it is three. But we are having the two valves in a series. So, your s becomes here twice; q becomes three and then you can derive the expression and you can get the V d o value. So, this general expression is very very good, if you are exactly means correctly, you are deciding your commutation group. So, in this if you are assuming this is you are a voltage, let us suppose this is a phase; this is your b, this is your c. We are having here three-phase; a c is three-phase a c circuit. Then your corresponding secondary here, it is your a 1, I can say and here it is your a 2.

Because both are here corresponding to a; similarly, we can say here it is your b 1, here it is your b 2. And of course here, now it will be c 2 and here it is the c 1. With this now, you can see if one is conducting, again that numbering it is said we are firing this valves in such a fashion, in this order that we can fire one from top, one from here. And it is like suppose your one and two are conducting then, your third will be going to be conducting means one and two there, then we are going for your third here means, this will be half and third. So, current will be again going through this and here two, three.

So, it is the seconds of conduction means here if your 1 2, one pair of valves are conducting, then the second will be your 2 3 and here your 3 4 and so on so forth. So, the nomenclature here why 1 5 and 3 are done, it is only to take care. So, that this is easier to remember, nothing else you can number anyone, but that will be giving a very confusion. But here if you are writing 1 5 3 and 2 4 6, then you are getting here this way of conduction and you can just see, what will be the output voltage? Now if you will see, what will be the voltage? Let us suppose your 1 and 2 are conducting, how to get the output voltage? What will be the voltage here?

Now this is a 1 means, here b and the 2; where is the 2? This is 2 means, this voltage and this voltage is appearing here. Now what will be the output voltage? When your 1 and 2 are conducting; no, just I want in terms of instantaneous voltage first.

So, this is value now your 1 means e b, here I can say it is e b 1. Here plus e a 2, but I said the transformer is winding here by one twenty degree is displaced. So, if it is positive, it will be 180 degree of this. So, this is basically the minus will be appearing. So, I said here the transformer winding in such a way, if this is 0 neutral so, this will be positive. Here, if this is coming here this is 0 and nineteen is it is going to be added; the voltage is going to be under root three times. If you adding, then it will be magnitude will be less in the phasor diagram, just you imagine here. This is your e a; this is your e b; this is your e c. Now your e a, here what we are getting? e b minus e a means this will be going here, then this is your resultant value; if you are going to add e a and e b to here, what you are going to get? Your output voltage will be less.

You see it here, just add these two vectors; one twenty degree displaced, your resultant will be this… but if you are subtracting, it is going to be under root three times of this magnitude is going to be… So, that is why it is made so, that we can get the maximum output voltage. If you are using the same, you can do it, but what will happen? Your output voltage will be less; this is another criterion we will see later that we should go for the maximum voltage output across the DC. Same transformer, same converter circuit should give the maximum. So, your output voltage here in 1 2, it will be this much. Similarly, if you are going for 2 3 you will find, it will be different means you are going to have six pulses and this is called the two way rectifier circuit.

And where we are using the two three-phase rectifiers one way; three-phase rectifiers where I am calling it is one way means, it is addition of this is one and this is your second we are taking care of.

Now, another configuration here; now instead of there we were using the two transformer, here we are using an extra transformer; that is called autotransformer and or it is also known as inter-phase transformer. What happens in the previous case? We secondary's were displaced by one twenty degree; here to introduce this one twenty degree. Here this inter-phase line is there means, if your voltage is appearing across this is a positive, this is your positive; this is your negative and this let us goes your neutral is zero. Now this you can see the upper portion and the lower portion is one twenty, eighty degree displaced automatically.

So, this voltage is going to add here this voltage and this voltage is going to appear here in this circuit. Major problem here you can see, this part is no doubt one way rectifier circuit; here it is in parallel. The previous case, it was in series that is why it was voltage was coming. So in this case, as I said the two groups are connected in parallel instead of series to the DC voltage here; they are in this way. The three-pulse ripple of one group here is going to be staggered here staggered with respect to other group. So, what happens? These three-pulses and another is going too staggered by certain angle; 30 degree we will see here and then it is giving the six-pulses.

So, this is also a configuration of six-pulse and here we are using an extra transformer that is autotransformer to introduce that is one twenty degree. Now this configuration becomes very very complex; Earlier people device some of the configuration like this, till you the bridge rectifiers were invented. So, people go for the different configuration; if you will see another one here, you can say secondary is having the six windings, six-phases means here the primary is three-phase. But secondary we are having the six-phases; they are displaced by sixty degree each in that one and then, we are conducting the valves and we are getting the voltage.

Here also, what is happening? To have this is a going to conduct; this one is conducting here; then we are getting this voltage means your return path here is not this, we are going for this one.

So, what happens? It is an each valve here is conducting; 1 6 of the cycle rather than 120 degree here, because others were conducting for 120 degree. So, what happens here? Now this you are going to conduct only for this 60 degree not for 120 degree. So, what is happening? Here the utilization of valve is not proper; it is a less utilize valve is only conducting for 60 degree and remaining it is half. But in other cases, it was conducting for 120 degree means valve utilization was better compared to this circuit and also the output voltage here is not high, because it is only one phase voltage is coming here. If whatever the voltage is there, this voltage is going to appear of the DC circuit, but in this case we are getting the six- pulses, because one is conducting at a time and we are getting the all. In this six-phase diametrical connection as I said here, the one valve is conducting at a time and here this is a pulse number is six.

You can see from this, here this is a if you are taking this as your phase a, here it is your phase b and this is phase c. Then corresponding the phases in six here phase of secondary. This will be here; I can say it is a 1 here, it will be a 2. It means, if you see a 1 and a 2 are this 180 degree phase displaced. So, you are this five once you are conducting, the two valves are conducting, then after 180 degree the five will become positive and then we are getting the six-pulses. So, here instead of pair it is one valve is conducting at time and the current is all the way, it is flowing here through the neutral of this transformer.

This circuit is now going to be complex, because if you are going for the large number of phases of the secondary or even the primary, the complexity becomes more and more. And even the one-phase there is some problem, then your whole this circuit will giving some sort of harmonics in this circuit. You know the harmonics will be more, if your output voltage is not a symmetrical.

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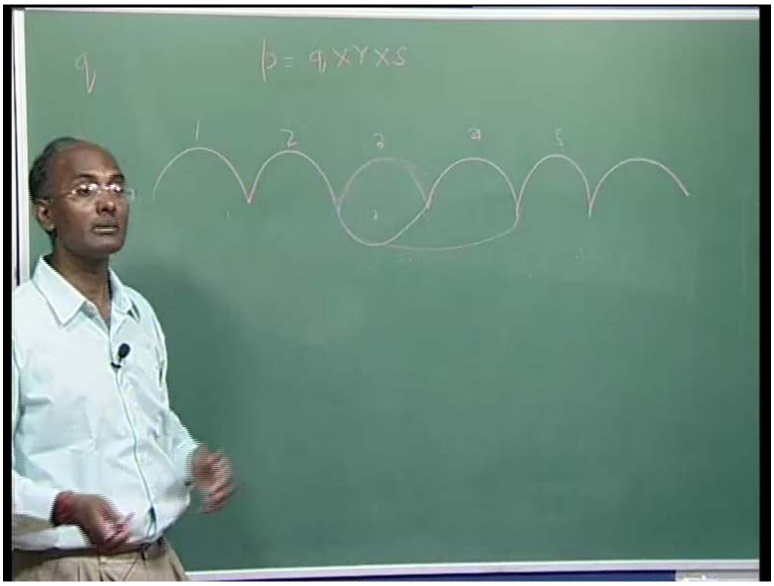

For example, If you are having this is your pulses, let us suppose you are having the six-pulses in a in the output of the DC. And due to certain problem, this did not fire and this is going somewhere here. Now due to this one cycle, if you will analyze the number of harmonics will be the certain different and it will be more harmonics will be there that will entering in the system.

We will see later on due to this sometimes even though your valve may not conduct due to certain problem, there may be possibility that here even though change over from one to two may not take a proper and finally, it is again one is continuing. For example, here your one is continuing, two is conducting, now the three was expected to conduct. There is a possibility that we get the pulse and this three did not fire, may be the different regions, and may be the voltage across this was not positive or may be other region. In the circuit, due to the weak system of there is also possibility and two continues here and third here, fourth gets again the positive pulse means, we are giving the pulses at the equivalent or to the valves.

Here the force was given again there is a possibility, the fourth may not conduct. We will see in the different conduct circuits, the voltage across four, sometimes it may be positive; sometimes it may not be positive. It depends upon the configuration of the force. So, there is a possibility even the two is again conducting and then after five we are again coming in the same cycle.

So, due to this mis-fire or some you can say not conducting of the valves, here you can see it is unsymmetrical. And one symmetrical means, there will be more harmonics that is going to be injected in the system. We will analyze later on and will found this process is self curing process. We never do anything for this, because after one cycle again we are coming back and complete symmetrical fall, a symmetrical wave shapes are coming. So, it is cleared automatically, but due to this we are getting lot of harmonics in the system that is not desirable.

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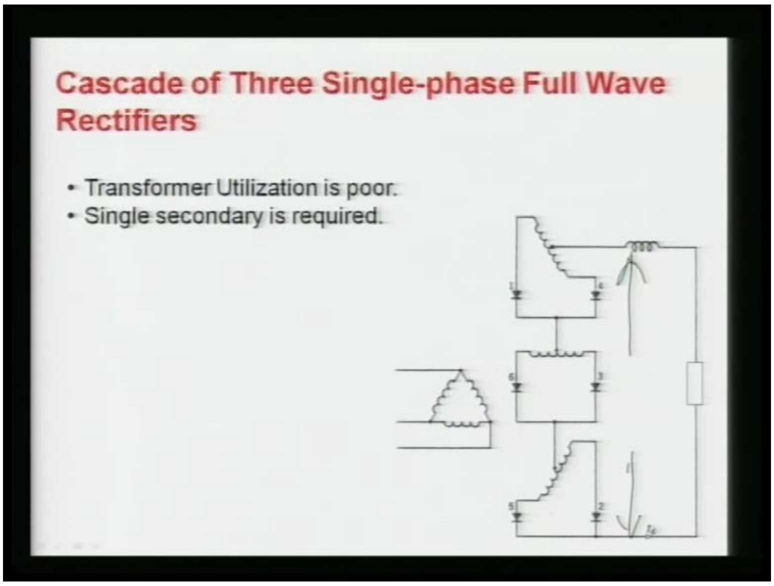

So, the proper protection or proper correction should be done for all these things. Another configuration here, you can see just similar to your single-phase full wave of rectifier here. If remember this is, let us go this is your phase a; this is corresponding to your phase a here and this is a center type transformer of the secondary and we are getting here. Similarly, here this is also center type of this b phase and this is corresponding to your c phases. Now here this is it looks this circuit is very simple and looks the larger voltage is going to appear across the output. Here it seems this voltage across here, it is large voltage, but it is not.

So, because you will find the total voltage which is going to appear depends upon the conductions. Again here, in this group only one will conduct; one, here one and here one then we will have a complete circuit. So, your output voltage here it is addition of whatever the portions are coming in the circuit; it is the voltage is going to appear here. And we will find, it looks the three voltages are going to be added here means, there will be large voltage, but it is not. So, because it is phasor addition; it is not at a just magnitude addition. And these phases are coming here, the voltages will in, it can be analyzed the voltage will be the same. Here again we are going to have the six pulses in this circuit.

Only here advantage that we are having only one secondary binding, but it is a center tapped.

So, we will be taking 1 by 2

What?

(( ))

The voltage just you have to … because if again it depends upon the, what is the tapping ratio here?

We will take the…

Yeah. If the tap is unity of this portion or is here half of this, then it will be added accordingly.

So, the output voltage just we have to add all these three-phases and that is will be coming and, but we are we will see the pairs here. It is going to conduct one here, one here, then we will get again the six pulse connection here. Only the problem here the transformer is half of it is utilized at time, because in that one and four it is half of the binding is only conducting the time; earlier it was complete binding was conducting. So, the transformer utilization factor, transformer utilization is going to be poor in the circuit.

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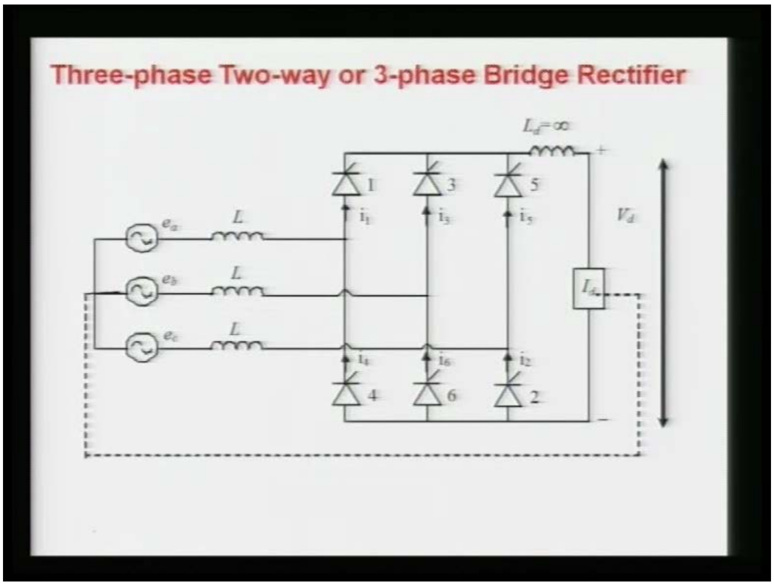

So, with all complexity and the various things, this circuit normally it is known as your gate circuit. It is very popularly used and this circuit is having a tremendous opportunity and we will see this circuit is only the best suitable for our rectifier circuit in HVDC link as well.

In this here, you will see now the number of q in this circuit will be, the q and this here again here in this upper portion, upper limb I can say, it is can be one commutating group; where the q is equal to 3. Similarly, we are having the lower here also we are having the three valves means, one valve in this group will be conducting at a time. Only the condition we will later on we will find that sometimes even though in this group, the 2 are conducting when there is a current is going to be switching from 1 to 3 here.

It will conduct, but here the commutation group is defined inter-ideal condition; it is the overlap is neglected. Overlap when means these two valves are conducting means the current which was flowing here, it was going to be shared by three here; that will take some time means to 1 and 3 may be conducting at the same time. That is called overlap period and will come later on and we will analyze the circuit properly.

So, here the q is 3, what will be the s? s will be two of course, because you will see here in one valve is conducting let us suppose this is conducting. So, this is coming here and then finally, it is going may be your 1 or 6 it is conducting here means, the two voltages and the two valves are coming together. So, s will be two and then, you can find the output voltage here is double compared to the previous case, because now here q is same. But here s going to be two so, the output voltage also becomes very high is the double of the one way rectifier circuit. To visualize this, this is almost similar to again the two one way rectifier circuits.

Now you can see in previous case, here the three windings are connected with the three valves and then there was a neutral so, one portion here half and now you can even another portion below. So, this is nothing but the connection of two three- phase one way rectifier circuit. Since they are connected in such a way that the current here; if this voltage, load voltage is same here. The current will flow here rather than here, because this will be the negative side. So, this can be open and now this becomes your bridge rectifier circuit which is very, very popular. And we will see this is a six pulse bridge rectifier circuit useful for our HVDC link as well.

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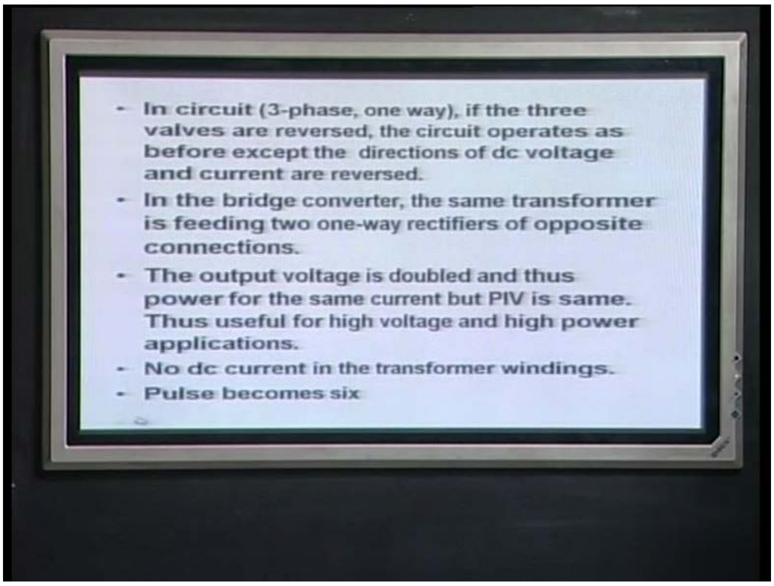

So, I can tell about this circuit means in this circuit, it is a three- phase one way rectifier circuit. In that circuit, if there are valves are reverse as I said, this one portion one and the lowers are reversed. Then circuit are placed at the same as before only the direction of DC voltage and currents are reverse means, one way rectifier circuit here I am talking about three- phase one way rectifier circuit. So, one way if it is a reverse, then what happens? The operation is not going to change; only the direction of DC voltage and current it is going to change.

So, what we are doing? The one positive and then we do the reverse we are adding. So, the current is going in the reverse direction in another valve. So, this becomes your bridge rectifier circuit. Here it is the same transformer is feeding two one way rectifier of opposite connections. As I said that is the similar the output voltage is doubled due to the s is equal to two. And thus the power of the same circuit here the, here another will find the peak inverse voltage is also same with that one.

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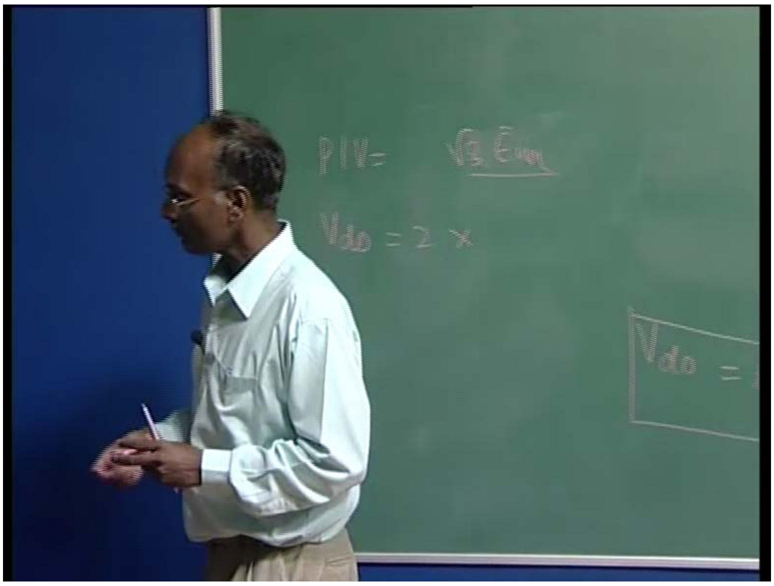

It means it is you are under root 3 E m in this case; it is not going to change. But your V d o is going to be twice of the previous case means it is you are the previous case here. So, that is why this circuit is very useful for high voltage application. And your high power high voltage means, if you are going to increase the peak inverse voltage for the high voltage, then the cause of rectifier circuit or cause of your valve is going to be very very high means, we have to design for the peak inverse voltage.

Another advantage in this circuit, if you will see our in the analysis of the current which I did in the previous lecture, we found there is some DC current in the secondary of the transformer. But in this case, there is a no DC current in the secondary of the transformer in this circuit. Again we will analyze and we will find that is here, because always we are having the current that is sorry it means we are getting the AC current. And the pulse here becomes six is the six pulse rectifier circuit

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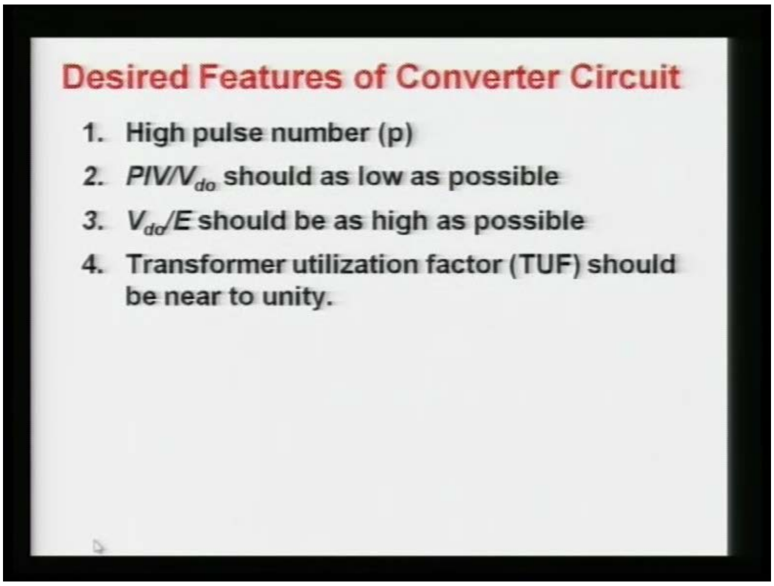

Now, let us see the summarization of complete all these circuit analysis, we require these four features for any good converter circuit means we require the large number of pulses. Large of pulses, why require large number of pulses? That it will reduce the harmonics AC side as well as the DC side. But it is also not possible that you can go very large number of pulses, and then your circuit becomes very, very complex.

So, we have to think, we have to go for the optimal number of pulse numbers normally the six pulse converters are very, very good, because the six pulse and then we can see other the desire the merits or features of converter circuit, six pulse is optimal. But at the same time, we can make the two six pulses and we will shift by certain angle means 30 degree, we will get the twelve pulse. It means, I want to tell here this is your six pulse, we can have another six pulse. But it is here it is starting your zero and shifting here.

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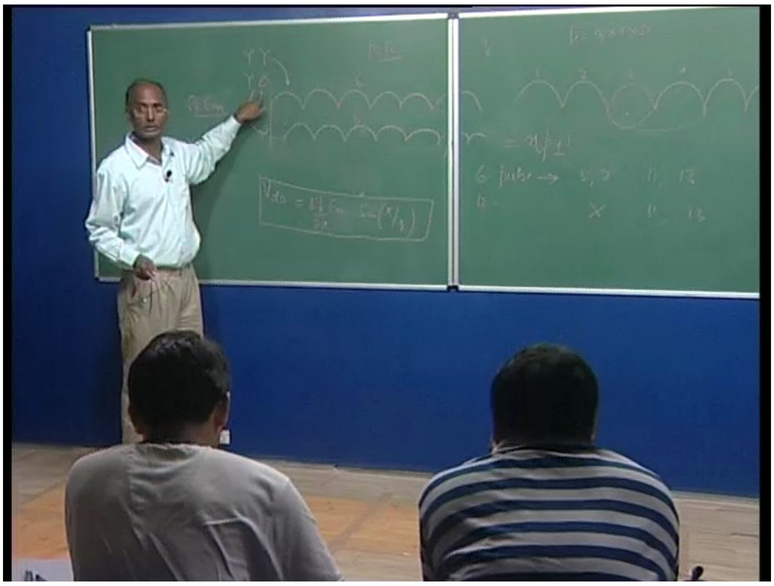

Because this is your 60 degree and 15, 30 degree means we are having this and we are going to add, then in one cycle; we are going to have the twelve pulses. This two six pulses are added together and we have a very good feature of the three winding transformers. That if one transformer is your star another is your star delta; this corresponding to this and this corresponding to this and then we are putting in the series, we are getting the twelve pulses. That is why most of the HVDC links they are operating on the twelve pulse converter basis.

So, here one transformer here, because already star delta as we know. That due to the star-delta transformers some there is a 30 degree saved. Again it depends upon this leading or lagging depending upon the winding configurations, how it is placed in the core, but certainly, there will be 30 degree saved. And due to this, we are now going to have the twelve pulses; here six, here six and the total pulse number is twelve. So, if you are going for the large number of pulses here, the harmonics only advantage of the number of pulses; if you are going to more means, it is a just like a here the DC output becomes more smooth.

And at the same time, here you the DC harmonics as well as the AC harmonics, DC harmonics is the basically harmonic that is appearing across the DC line and AC is that is going to be reflected back to the transformer and then finally, going to the AC circuits. So, both in this case the twelve pulses are better than six pulse and we will find we will see the harmonics component in the actual operation circuit. And we will find normally as all even though in beginning, I said the harmonics component for the six pulses it is your n p plus minus one is very common. Here if you are going for twelve, now you can see n is your integer value means it is a 1 2 3 4 5. So, if it you are going for the six pulse cases, you are going to have your fifth seventh we are going to eleventh and thirteenth and so on so for.

Now, if we are going for the twelve pulse, here you will find this is going to be cancelled and we are having this and then and so on so for. What happens? This is basically going to be cancelled by the star-delta transformer connection itself means that is not going to the AC side due to that (( )). So, this fifth and seventh will not appear in the twelve pulse operation, due to this phase swift here; it will be cancelled whatever it is generating it is a cancelled by this one negative volts. And if you adding together, that will be going to zero means it is not going to enter in the AC circuit. So, now, you can see the harmonics component is going to be here, few harmonics are eliminated automatically with this configuration.

And also if you see the magnitude wise, those are the lower harmonics component having the higher magnitude will again analyze that the magnitude of this harmonic current will be more compared to this. So, the magnitude here also going to reduce and some of them cancel. So, the twelve pulse operations normally used in HVDC link. Again this twelve pulse operation is nothing but your operation has six pulses and having the two transformers and connecting the series in the secondary side.

Another requirement is your this peak inverse voltage should be as low as possible. The reason is obvious that if the peak inverse voltage is less here means we are going to have a less costly your valve, means this side directly the cost of the converter. Because the converter is consisting of your valves here; if you are going for large peak inverse voltage means, you are the cast of whole circuit is going to be more. Now here why I am making the PIB where upon V d o? Because the V d o here we require this output voltage should be as maximize as possible.

If any circuit which is giving more DC output voltage that is a better for same configuration. So, this V d o should be as that is why third here, you can see the V d o by E is nothing but your RMS value means E it is your E m by under root two. So, V d o here E is nothing but, I can divide by here E; it is your what will be this here into under root two. We want this value should be as less as possible, because if it is more means and this E is the impress voltage in the transformer secondary. And this V do which is coming out of the rectifier circuit and this is more means for the small amount of secondary transformer winding; we are getting more DC output.

So, this value you want much larger and you see it depends upon the only two values; it is s and q. So, normally we use the here we will see the q is it can go for the q six option under the thing, we will analyze for all the possibilities of q r s. Here for a given let us suppose six here, your six pulse converter what is the possibility of your q r and s? It can be six here, it can be one here and one means it is six again; it can be here 3; it can be 2 1; here it can be 3 1 and 2; here it can be your 2; here it is your 3; it one; here 2; here 1 into 3. So, we are having this all five combinations and will find that we will see, here we are getting this is the optimal configuration. For all these four requirements, for all these four requirements, we will see for the different for even though six pulse.

We will also see for the twelve pulse, this is the best configuration which will give you these entire four requirement that is required for HVDC, because multiplication is always here six. So, the second here, which I am going to say here, the peak inverse voltage is basically not only we are talking about the peak inverse voltage. We are talking the ratio of the peak inverse voltage divided by this factor should be as minimum as possible. Because we want this more, we want this minimum. So, the ratio we are talking, because again this is a related with the valves. So, here this peak inverse voltage is divided by your V d o should be as minimum as possible. And thereby, we can just reduce our cast of the whole rectifier circuit. Another term here it is the very important; that is a transformer utilization factor this is and it should be near to unity.

The transformer utilization factor is defined as you are the RMS secondary power divided by the DC power. You know, the DC power that is a V d into I d, it is the in denominator. And your output, this transformer this V t that is your RMS of your secondary winding RMS voltage multiplied by RMS current divided by your DC power; this should be near to unity, because the ratio of transformer utilization factor is just related to your efficiency or material efficiency of the transformer. Now you know then so many efficiency; efficiency here it is not only related to the loss. It is efficiency related to a material, efficiency related to your performance; so many things are efficiency also terms as not always is a p output upon p here. But here we are talking, p output the DC output divided by, no AC output of the transformer divided by the DC and that is your defining. So, this value is normally more, but the reverse is always less than unity.

So, this yours the transformer utilization factor is also equally important and that should be taken care. Now if you see, what will be your the peak inverse voltage? Divided by your V d o it will be nothing but, I can just write the expression for this.

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We will analyze; now I am telling it is a optimality is not defined here. We will see we will go for all these values. Again these four criteria, we will see because the first criteria we have decided that for the six pulse. Now for all these three that the peak inverse voltage like V d o; another second is V d o upon E. And this transformer utilization factor for all these five combinations, we will find the table. And then we will see which one is optimal? We are not going to optimize here; we will see, because it is not that we can have the three point two here. Because these values are set of your solutions will lie only in the five sets. And then based on that, we will choose which one is the best option?

In the next lecture, I will just give this table and we will see that this will be that the stop here and then why we will see the values and then we will analyze this. So, here you are the peak inverse voltage divided by your V d o for and again in terms of your q r s circuit. Now as I said we have to go for the optimal configuration, means your p inverse voltage divided by V d o, we have to write. Again this peak inverse as I said it depends upon your q whether it is odd or even; this does not depends upon your q, what is the value, because thus your V d o is nothing but is a simple it is your E.

So, we can just write for the two values. One I can write here; q is even and here q is odd and we will find the expression for this. It is your, in this case it is your twice pi divided by s q sine pi over q and here we will find this pi divided by s q sine pi over twice q, when this is odd and even. Here thus this is a derived basically, the based on the expression this. And already I derived here your PIV I said it will be your 2 E m; when q is when q is your even. If you remember and then simply you can divided it here. When your q is even and we can write here, what was this expression? This sine pi over q, here thus value 2 it was 2 even; q is your odd.

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Here cos 2 q.

So, just you divide this expression, from here E will be cancelled and you will find only we are getting here even though E is not appearing, because there is a ratio of the voltage by voltage. This is also voltage; this is also voltage and we are getting this one. So in this case, here as I said q is also coming two. So at that time, you have to take this expression when the q is your this; when it is q is free, then we have to take this. Here it is again even, and then you have to take this. So, you can write all these values for the, because q is decided for q s and the p is already fixed, you will find what will be this value.

So, this is basically your this consideration here. This directly as I said here, we derived this expression. Only here the transformer utilization factor that I will discuss the in the next lecture, because here we have to go for the RMS value and other things and in this RMS value, now in the transformer utilization factor, you can see till now we have not used r at all. Here in these two expressions no r, but now r is going to p here, because r is related to your current and current is whether the parallel circuit or it is series circuit; the current will be different.

So, in this transformer utilization factor, we have to consider now r s and q as well, and then we will see we will go for the different options. And then, we will choose the optimal configuration. So, the in the today's lecture, I can summarize we saw the various rectifier circuits; three-phase rectifier circuit and we just generalize this whole output voltage in terms of the commutation group; that is a q, the series valves, the parallel valves. And we saw, what will be the valve voltages and that will be also required. We also saw the pulse numbers and finally, we just I came here and means came on this conclusion.

That we require this four desired features for any converter circuits means we require the last number of pulses. Again we cannot go for infinite number of pulse, we should limit our, because if you are going for large number of pulse, your transformer configuration and the connection becomes very, very complex. So, we have to go for the simple circuit, at the same time we should require the large number of pulse to reduce the cost of whole your converter circuit.

Seconds we want this peak inverse voltage divided by the output DC voltage without delay should be as low as possible, because the peak inverse voltage here; now question here, why we are not only looking for the peak inverse voltage? We are going for the ratio; because of it is sometimes we want this is the higher value. Even though this is higher and this is also slightly higher that is even though acceptable value.

So, that is why here we are going for the output voltage and peak inverse voltage divided by output voltage should be as low as possible. Third requirements thus the DC output voltage should be as large as possible and force requirements that is very important is the transformer utilization factor should be near to unity; means, it should be very near because normally this factor if it is larger, we do not want.

We want it should be near unity. This basically your this rectifier circuit which I called the bridge rectifier circuit is basically, this utilization factor is the best in the bridge rectifier circuit. That is why it is used very properly and in these circuits, all almost all of the applications. So, with this I finish here and this ends yours lecture two of this module two. And we will see now all these performance the optimal configuration for six pulse and the twelve pulse converters in the next lecture. Thank you.