Advance Power Electronics and Control
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Lecture - 34
Matrix Converter II

Welcome to our lectures on advance power electronics and control. We are going to discuss matrix converter. We have started our discussion in your previous class, will continue to discuss of the matrix converter. This was matrix converter topology we discussed in the previous class and we have discussed about how does it work. Let us see what are the features of the matrix converter.

It generally consists of 9 bidirectional switches which allow any output of the phase can be connected to the any input and thus you can constitute different frequencies of the three-phase waveform.

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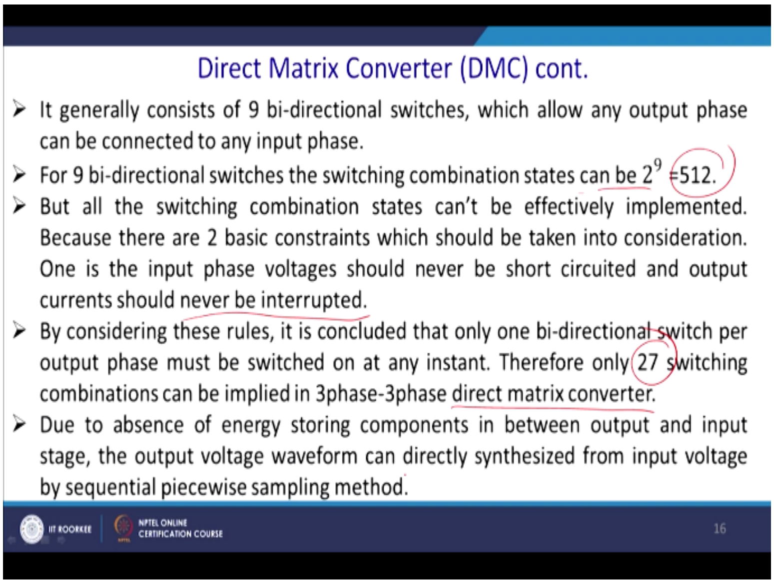

Nine bidirectional switching combination of states you know can have high rate of redundancies. So you can have as high as 2 to the power 9 combinations that leads to actually 512 combinations. So we require to understand that but all the switching combinations states cannot effectively implemented because there are two basic constraints we should be taken into the consideration.

One of the input voltage should never be short circuited and the output content never be interrupted. So these are the two conditions are primary condition we required to (()) (01:58). Considering the rule, it concludes that only one bidirectional switch power output must be switch at an instant and thereby only from 512 it will reduce to only 27 switching states can be implemented in three-phase to three-phase direct matrix converter.

Due to the absence of the energy storing component, the in between output and the input voltage of the waveform can directly synthesize from the input voltage by sequence of the piecewise sampling method. So you have to for piece or will see that how that waveform is generated in coming slides.

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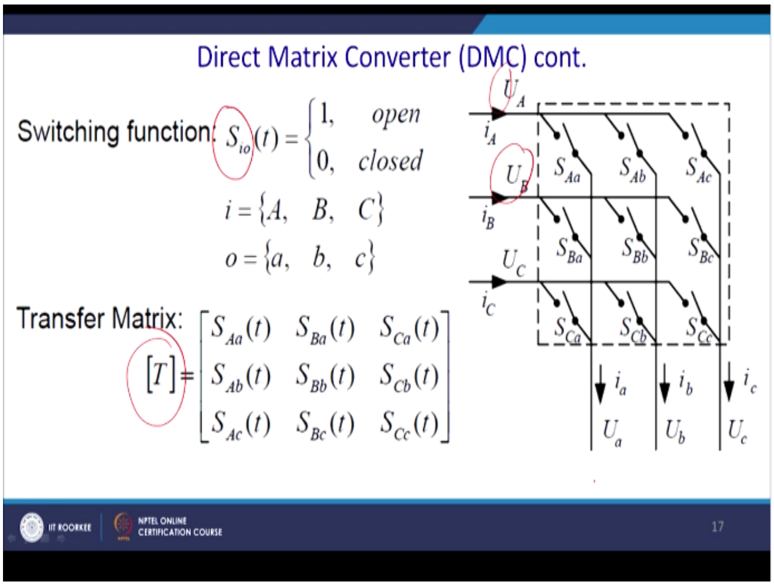

See that the switching functions so this is the input to output. If 1 it is open and 2 it is closed. I is your input that is capital and lower small letters are for the output. This is the transfer matrix. If you wish to get this UA at this output voltage, then you will short Aa and if you wish you UB to get in the U small a on in output, then will short Ba and so on and thus you can generate a different kind of voltages. If you have same frequency conversion, then this switch, this switch and this switch will be short.

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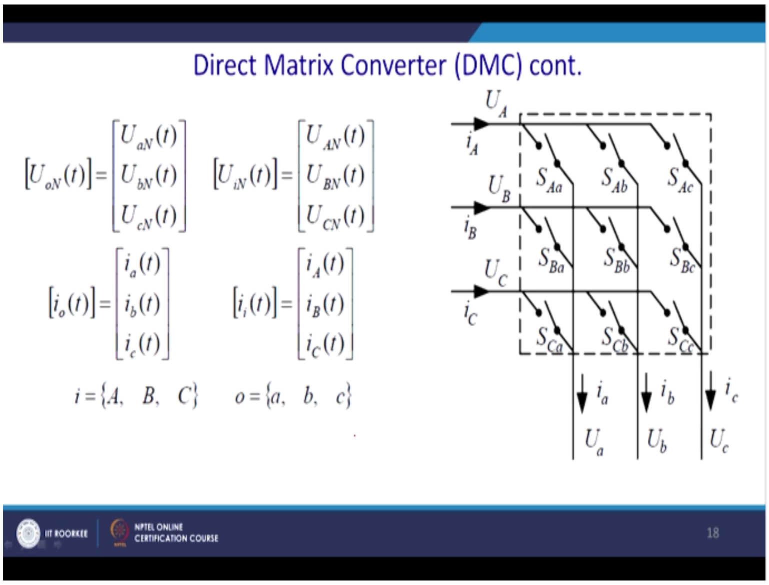

And so this is the actually the output voltage matrix and it is not that actually you can have asymmetrical configurations, mostly it can be used for the multiphase more than three-phase electrical machines, five-phase, six-phase. So you can have a more number of output legs also, that is also possible. So you have UaN, bN, cN and this is basically the output voltage matrix and you have input voltage matrix that is UAN, BN, CN and this is the current and this is the voltage.

All the capitals belongs to the state of the input site, all the small letters are belongs to the output sites. So this is our convention we are following.

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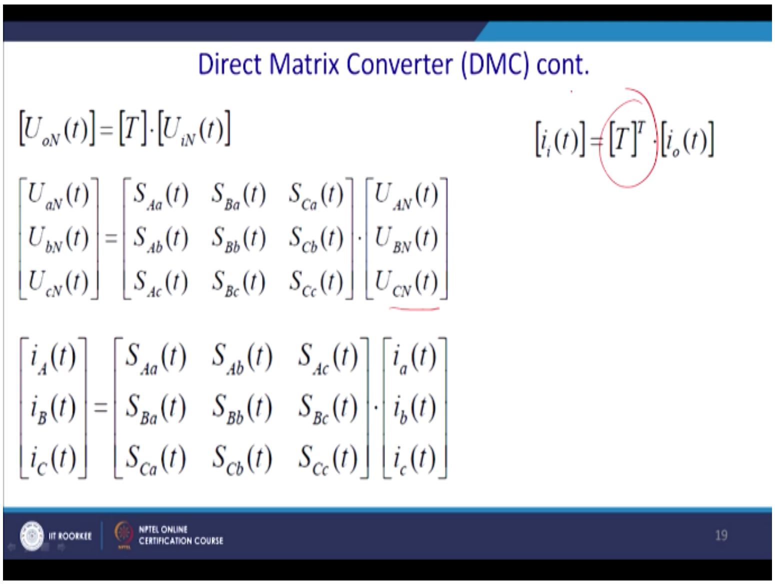

So this is the overall transition matrix, UaN=this transitions matrix of 9 element considering that it is three-phase to three-phase conversion. Of course, you have a three-phase to five-phase conversion, you can have that kind of conversion also exists and thus you can apply this. Now this is for the voltage and this is for the current and of course if you wish to have a current then you have to take a transpose of this T matrix to get the input and output relations.

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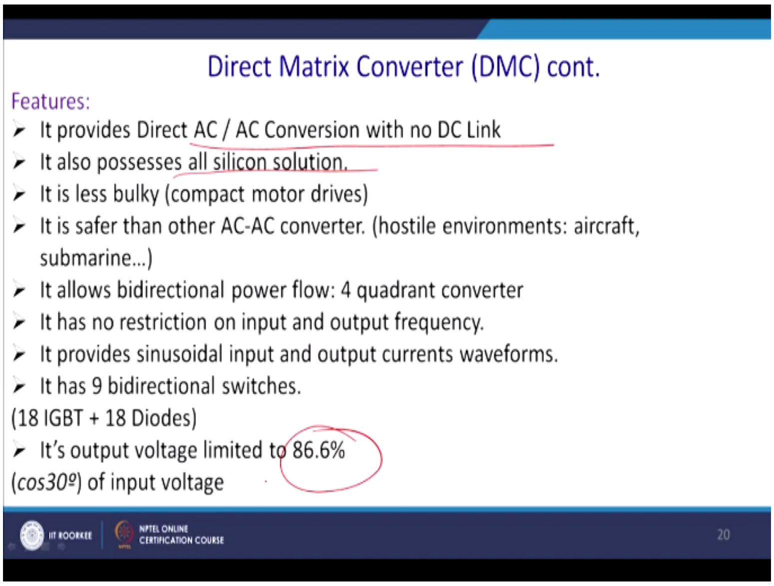

What are the features of the direct matrix converter? It provides definitely what has been mentioned direct AC to AC conversion without the DC link. We have not put any DC link. It also possesses all silicon solutions or silicon carbide solution or GAN solutions so it is quite compact. It is less bulky and very compact for the drives applications. It is safer than other AC to AC conversion, hostile environment like aircraft, submarines where actually aircraft where it is a very big issue, (()) (06:16).

It allows the bidirectional power flow also. If you have a regenerative operation or somewhere, you can always do that because all the switches are bidirectional, all the four quadrant operation is possible. It has no restrictions on input and output frequencies. So if you choose the silicon carbide based devices, you can run induction machines may be as high as 1000 hertz.

So instead of the 50 hertz and see that what will be your power level, straight away same machines can be increased though two times power where it is quite amazing features you know so 1 kilowatt machines instead of the 50 hertz if you manage to run of course you have to sustain the insulation level so you can run at 20 kilowatt so that is a quite remarkable phenomena.

As far as the drive side it is okay so machines design requires to be changed taking care of the high voltage level of penetration. So it provides a sinusoidal input and output current waveforms and you will find that actually since it can be switched at high frequency and so it can be perfectly suited for the wind energy applications what you have a variable supply of the wind and does you generate maybe 10 hertz, 12 hertz, 15 hertz depending on the wind speed, so it is connected to the grid, output is always 50 hertz.

So that kind of conversions actually works very well with the matrix converter. It provides sinusoidal input and the output current waveforms and the size of the filter is quite low, will show different voltage and simulation results of the few matrix converter and it has 9 bidirectional switches. So it has 18 control switch that is IGBT, IGCT or whatever maybe GTO and 18 diodes.

Its output voltage that we shall discuss about it, it can only buck the voltage but you can of course we have studied the Z-source inverter that concept can be also included here and thus you can increase the voltage level but without materializing the concept we have eventually may thought so that restricts the modulation index here in case of the matrix converter that is restricted to 0.866.

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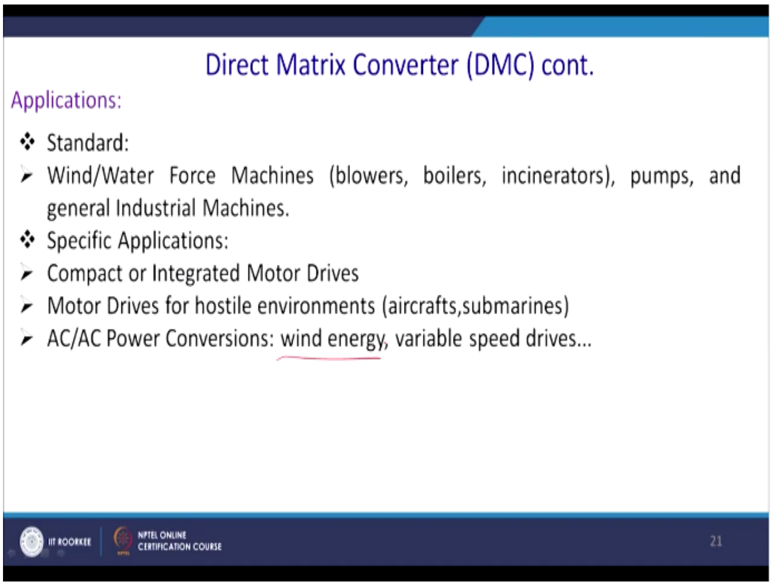

Now what are the applications? There is a wind applications, water force machine blowers, boilers, pumps and general industrial machines. Specific applications like compact and integrated motor drives. Motor drives for the hostile environments and also where mass or the weight of the component is quite plays a significant role of choosing a component. AC to AC power conversion is wind energy and other variable speed drives.

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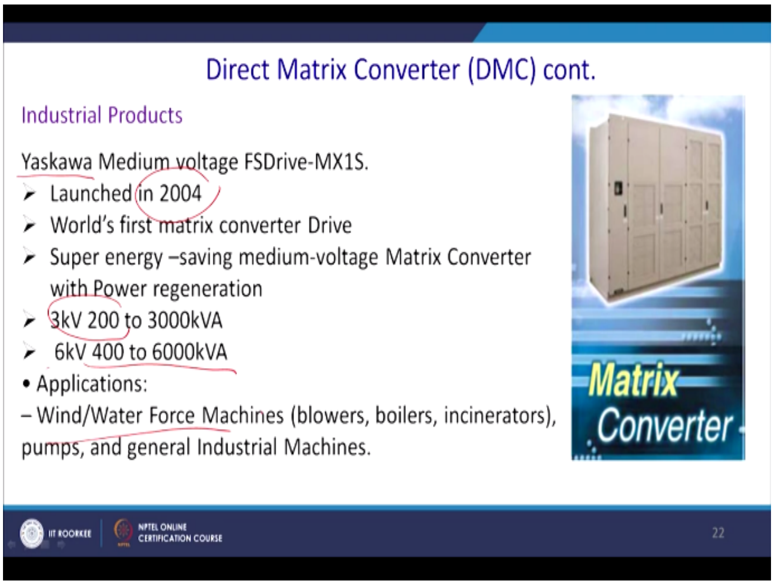

Now we can show this already been put into the industrial applications of the matrix converter. I am showing pictures of Yaskawa medium voltage FS drive MX. So it is launched you know around 14 years ago in 2004 world's first matrix converter drive. So it has been observed that super energy saving medium of the voltage of the matrix converter with power generations that is to the level of 3 kV to 200 volt.

And kVA rating is basically from 200 to 3000 kVA and also 600 for this 6 kVA you may have actually this matrix converter rating is 400 to 6000 kV. Applications are the wind, water, blowers and all the industrial applications.

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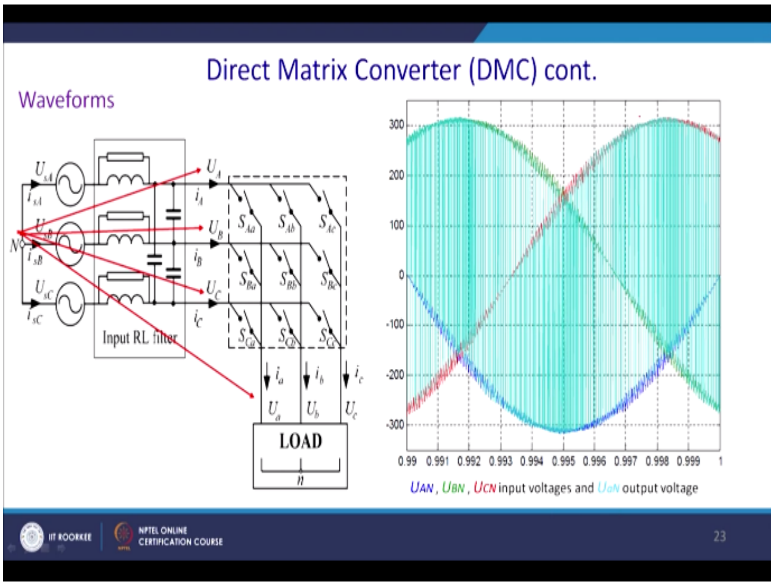

Now see that how we will generate different voltages. UAN, UBN and UCN are the input voltages and output voltages are U small a N. So you will be triggering in between quite high frequency because it was thyristors you are not allowed to trigger, you were allowed to conduct for an alpha of 15 degree, 20 degree, 30 degree but you can switch very accurately and generate the shape of the voltage as required.

And since it has a very high frequency harmonics, it will be naturally eliminated with the help of the low pass filter and low pass filter also will have a little high cutoff frequency and thus it would not be bulky. So you know this is UA, this is UB, this is UC and this has been shown into the different color and ultimately you get the envelope of UAN.

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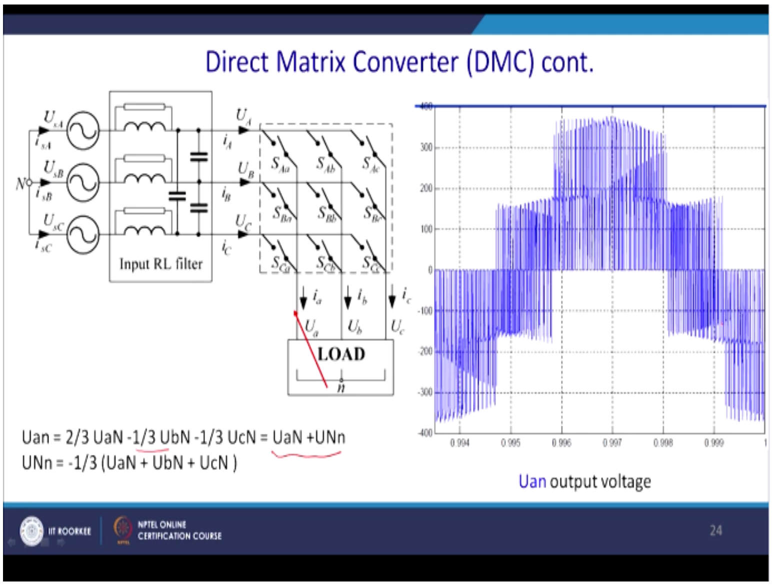

So this is the case of Uan output voltage by switching. So Uan=2/3 of U capital AN-1/3 of UBN-1/3 of UCN so you can add up to that neutral voltage and thus the neutral voltage will be basically 1/3 of this UAN, BN and CN and ultimately this is the way you generate a direct matrix converter.

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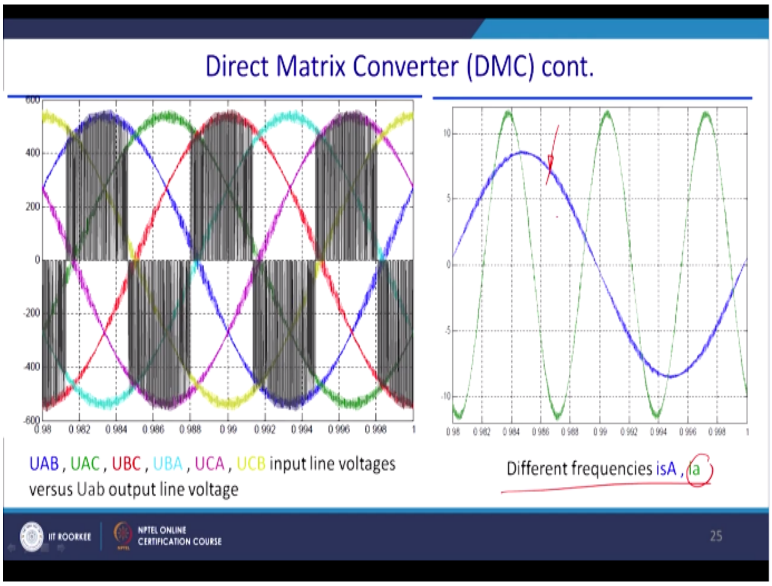

So this is the applications of it so here you switch in a such a way that this has been switched for this part this coming from there and accordingly you will switch and you will find that actually voltage and current and it have a different frequency of input and current. So this one actually your all the small letters are essentially are the output sites. So green one is your output voltage but frequency was increased and this is the input site and you can see the lower frequency.

So essentially it is the stepping up the voltage of the converter, stepping up the frequency of the current, so here it is quite applicable that is a typical application of the wind form application where your inputs this is the input and you know you may have a 15 hertz and you are converting into some other frequencies. So higher frequency may be most of the cases and thus you will change it with the help of the matrix converter.

And see that it is quite smooth since because of the high switching frequency of the matrix converter. So this is the applications.

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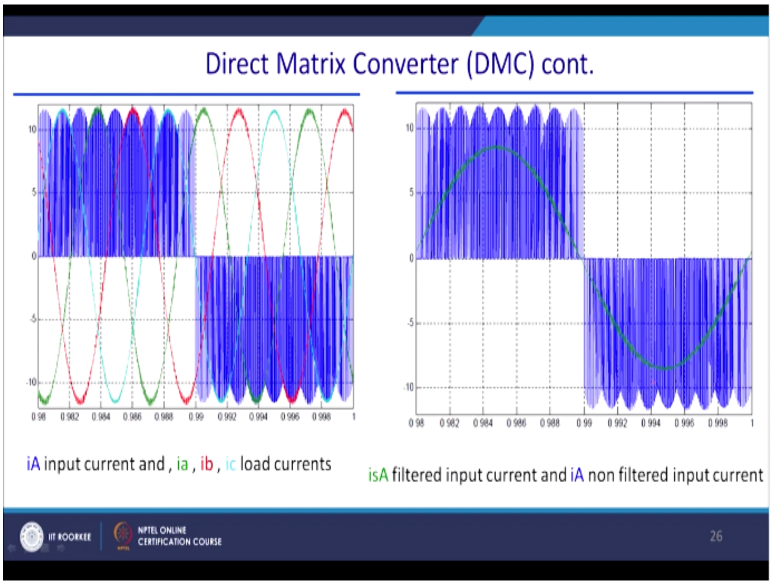

So this is actually a three-phase waveform for input site and ultimately you generate blue one as your output and you are basically now reducing the frequency of the output voltage and you can actually get this is your input and this is your output voltage.

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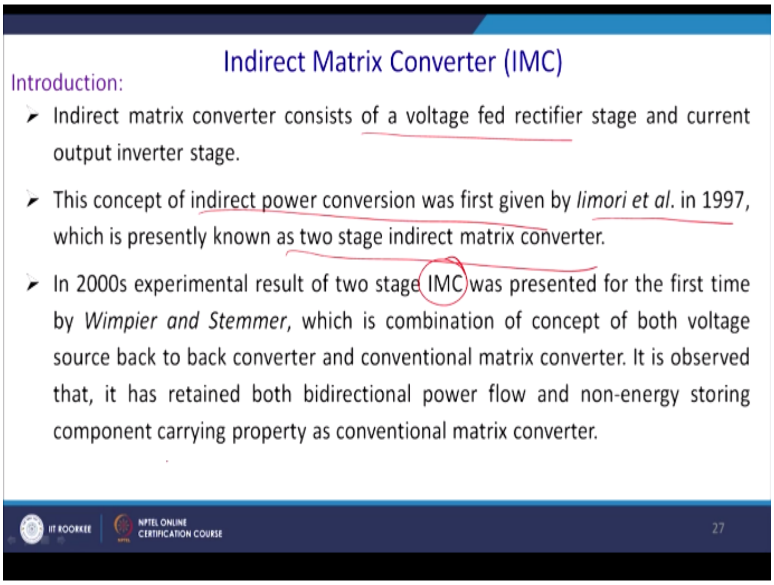

So now let us talk about another topology, quite interesting one that is indirect matrix converter. There are few disadvantages of the direct matrix converter and that will be discussed and then will take out the indirect matrix converter. Indirect matrix converter, so what are the limitations of it. There is a problem of circulating current and for this reason the direct matrix converter in both the end you require to actually put the capacitor in parallel.

So that once you are switching actually one switch is to the another switch you require to give a path, otherwise that current should sink to the capacitor so that makes you know the basic purpose get defeated and make some time this capacitor required to be sometime required to be bulky depending on the rating and also actually detect itself with the time and thus it actually further allow us to investigate indirect matrix converter.

So indirect matrix converter you know is a matrix converter consisting of the voltage fed rectifier stage and current output inverter stage. So first part is same, it is basically VSI and thereafter you will have a CSI. The concept of the indirect power conversion was first reported by Limori et al in 1997 and which was precisely known as two stage direct matrix converter.

If you have IEEE access, so kindly go through these papers, quite interesting you can find it out that will be quiet great to understand the concept. They in 2000 the experiment results of two stage indirect matrix converter it will be abbreviated here IMC, there it will be abbreviated there as DMC, so it will be IMC was presented for the first time by Wimpier and Stemmer which is combination of the concept of the both voltage source back to back converter and conventional matrix converter.

It is observed that it was retained both bidirectional power flow and non-energy storing component carrying property of the conventional matrix converter.

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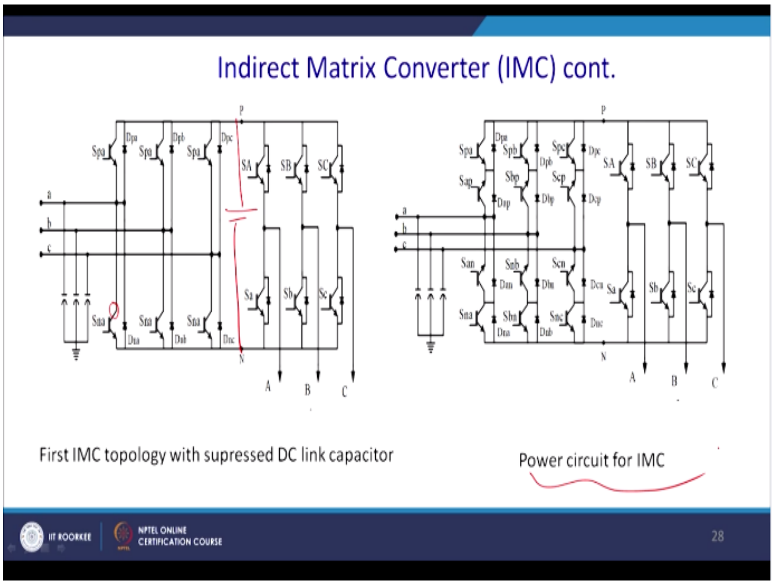

Now see that so this is basically the IMC topology, it is nothing new, only this DC bars here is missing but how you generate the DC bus voltage without the help of the capacitor, that is the challenge and that is done by the control techniques, so thus it has got superiority of the conventional DC to DC converter. Now there are the few more advantages like you can scale up to the multilevel inverter.

Because you require you know we are actually conventionally use the drain of the IGBT with the source of IGBT, that is actually the form of the leg which is available in the market and same combinations can be used but advantage is that you can scale it up if you require higher level that is basically the three-level in this site and you may have if you find that okay this rating will be sufficient, so you can actually have a lower rating here.

So this is the power circuit of the IMC. So these are the few flexibility is there in case of the indirect matrix converter.

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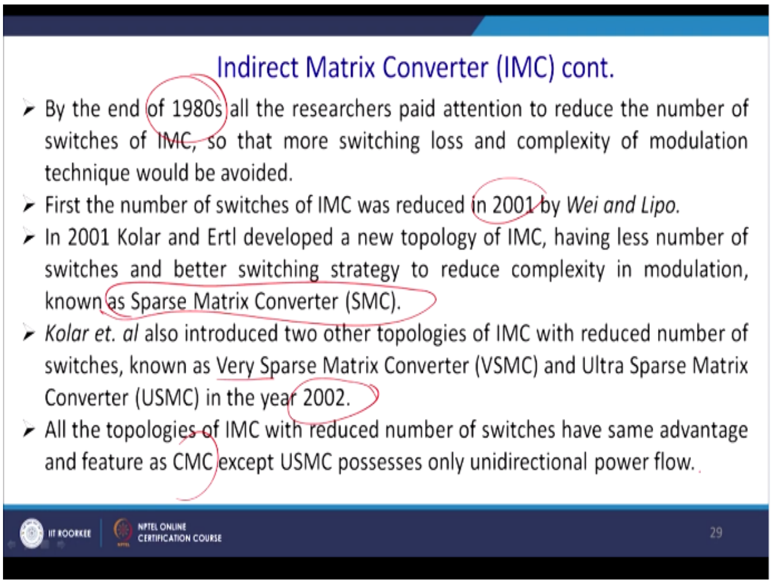

So few interesting features of this matrix converter indirect matrix converter, by end of the 1980s all the researchers paid attention to reduce the number of the switches of the indirect matrix converter. So that more switching losses and the complexity of the modulation can be avoided. First the number of switches of IMC was reduced in 2001 by famous scientist that is Wei and Lipo.

In 2001, Kolar and Ertl these are the German scientists developed the new topology of IMC having less number switches and better switching strategy to reduce the complexity in modulation and it is known as sparse matrix, quite important development in case of the matrix converter and Kolar et al also introduced the two other topologies of the IMC and reduced the number of the switches known as the very sparse matrix converter.

These are some derivatives of the sparse matrix and ultra sparse matrix in 2002. All the topologies of the IMC with reduced number of switches have the same advantage and the features of the actually this CMC and except USMC only to unidirectional power flow but in matrix converter we have a bidirectional power flow.

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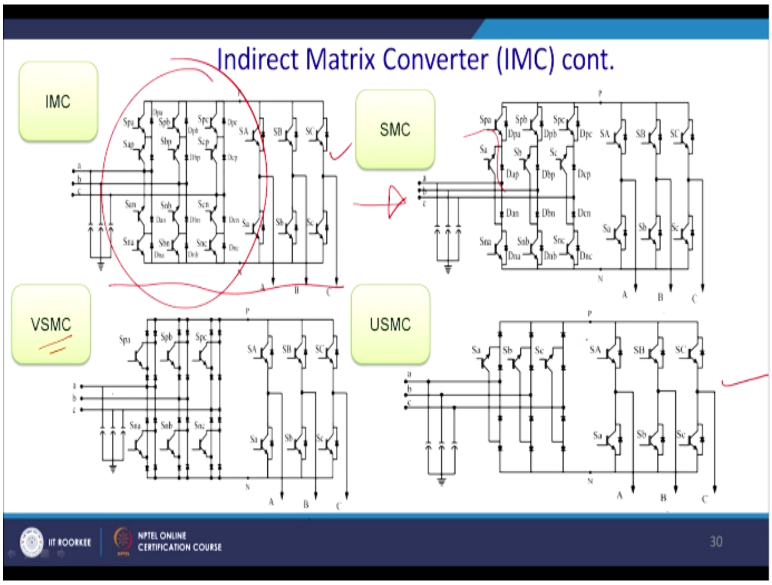

So that is the one of the challenge. You see that this is basically direct matrix converter, it is basically VMC, sparse matrix, it is SMC it is UMC. So see that a different configuration in a diode has been done. Since you want to make current so all the attention was paid to reduce the number of switches. So here is a normal IMC so this part is a three-level normal rectifier but without the DC link and two level inverter.

But see that the changes here in this SMC so these some switches some portion of the switches is required to be common. So you see that actually there is this diode configuration is same here, here diode configuration has been changed and also you know there is a path to flow in this way but reverse path is not allowed and it should be allowed through this switch. So in that way it makes the power flow bidirectional and this is basically the SMC.

And this is further development of SMC over it because it consist of see that all the development in this part and it consisting of actually one leg consisting of 4 switches so you have 4 switches and the 4 diode so this have total 12 switches and 12 diode. Here you know you will have 9 switches so you basically reduce the 1 switch into the system but number of diode it essentially remain same that is 4.

Here in this configuration number of switches is 6 but number of diode is little more and this is called VMC and this combinations you know it is called USMC all these upper legs are controllable or lower legs are controllable which it is something like your half controlled converter. So you can control by this and you can generate a fictitious DC link voltages and thus it can be operated based on these operations.

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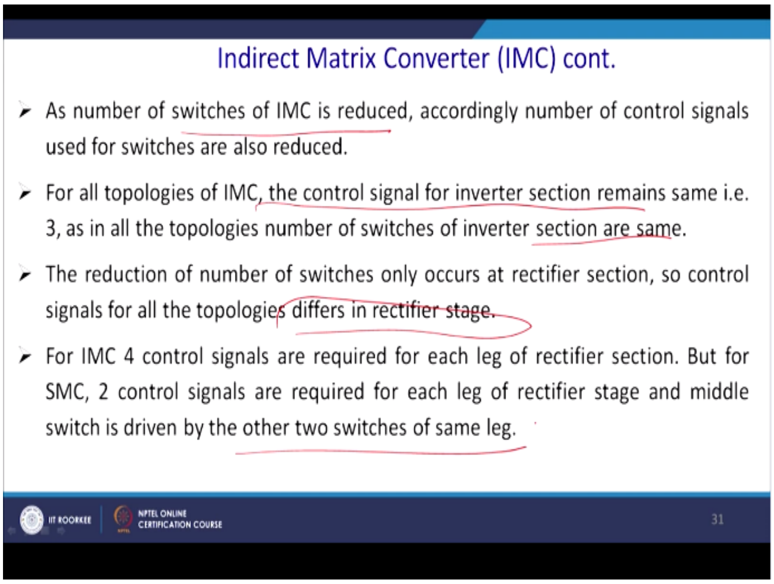

So from discussions we can say that as number of switches of IMC is reduced accordingly number of control signal used of the switches also get reduced. That is quite trivial statement. All these topologies of IMC the control signal for the inverter sections remain same. That means 3 as well as all the topologies number of switches of the inverters are same. The reduction of number of switches only occurs at rectifier sections so control signal for all the topologies differs in only the rectifier stage.

So there is no change in the control stage. The IMC 4 control signals are required for each leg rectifications but SMC 2 control signals are required for each leg rectifier stage and middle switch is driver by the other two switchers of the same leg.

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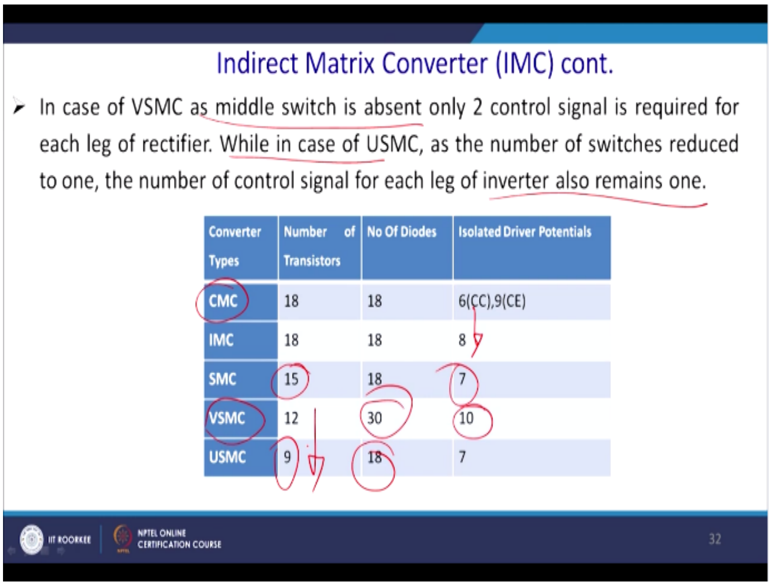

Now control of those all the topologies it is not possible to discuss with the shortage of time but some actually comparison on these features has been actually discussed here. In case of the VSMC as middle switch is absent only 2 control signal is required in each leg of the rectifier it is something like half-bridge converter. It is something like two-level inverter or converter. While in case of the USMC, the number of switches are reduced to one so number of control signal for the each leg of the converter remains only the one.

So if it is CMC type converter, so you require 18 transistors and 18 diodes and so thus you require 9 isolated drivers. Here in IMC, you require first case you require the same it is 18 and 18 but number of isolated driver is required to be a 8, that is quite reductions from this normal direct matrix converter. So SMC you require 15 and number of diode is actually number of diode is basically 18 but isolated supply you require 7.

And here it is drastically reduced, you can see that number of switches of VMC is 12 but number of diodes will be quiet high, you require as high as actually 30 diodes but isolated supply require only 10. So USMC is a further reduction in everything, you require only 9 and you require 7 isolated supply and you require only 18 diodes.

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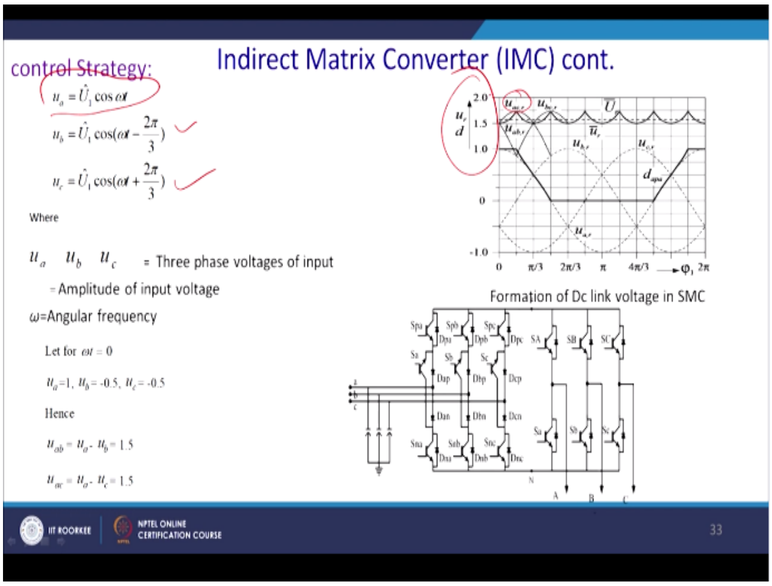

Now this is quite interesting phenomena, how you generate the voltages quite actually we were saying that there is a DC link voltage and how this DC link voltage will appear and since it is not energy storing element it has to be an instantaneous phenomena. So for this reason you know you can see that this is basically the control signal for phase 1 ua cos omega t, this is actually 120 degree phase shift, ua, ub, uc are the three-phase voltages and the amplitude of the input voltage.

Now see one thing here this is it has been actually reported here, see that this is you see uac and this one is uab. So once it is switched on, you know so here ubr will be positive and this will be actually again these signals will be applied here and thus you know it is just as the same as triggering on the thyristors so here in this configuration, the difference of this voltages of u ab, r and u ac, r will appear since u ab, r will appear across the DC link.

Similarly, here in this point, this is basically AC is the most positive phase and similarly at this point what will happen, u bc, r will be the most positive point that will be appeared across this DC link voltage and gradually will get a ripple of the 6 pulse and you require this will be the fictitious DC bus voltage and accordingly it will be actually changing to value per unit value of 1 to 2.

We shall continue our discussions with the control of the matrix converter in our coming class. Thank you for your attentions. Thank you very much.