Advance Power Electronics and Control
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Lecture - 35
Matrix Converter III and Power Quality Mitigation Devices

Welcome to our advance power electronics and control courses in NPTEL. We shall continue with your matrix converter and therefore we shall see that different kind of power quality issues briefly. So let us discuss what we have left, we are discussing with the indirect matrix converter. We have discussed different topologies. These are the recapitulations of the previous class.

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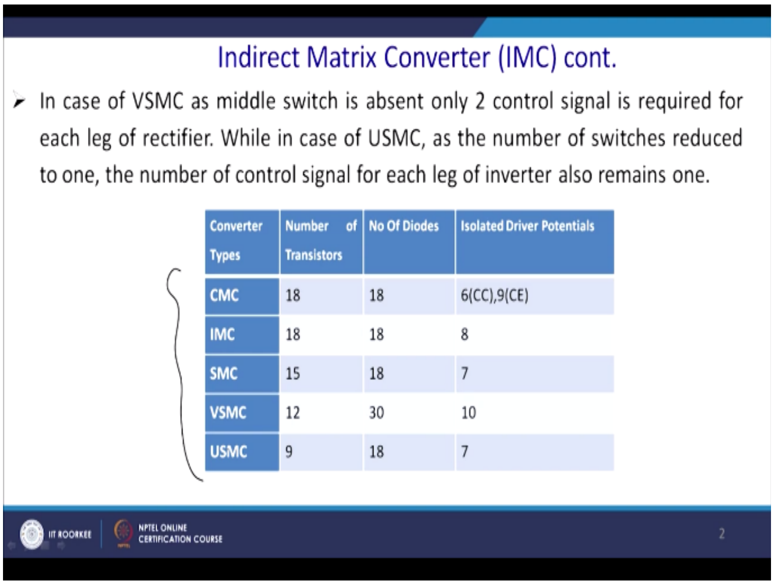

Converter Types	Number of Transistors	No Of Diodes	Isolated Driver Potentials
CMC	18	18	6(CC),9(CE)
IMC	18	18	8
SMC	15	18	7
VSMC	12	30	10
USMC	9	18	7

You know there are different kind of topology has been discussed and the switching count is also been discussed.

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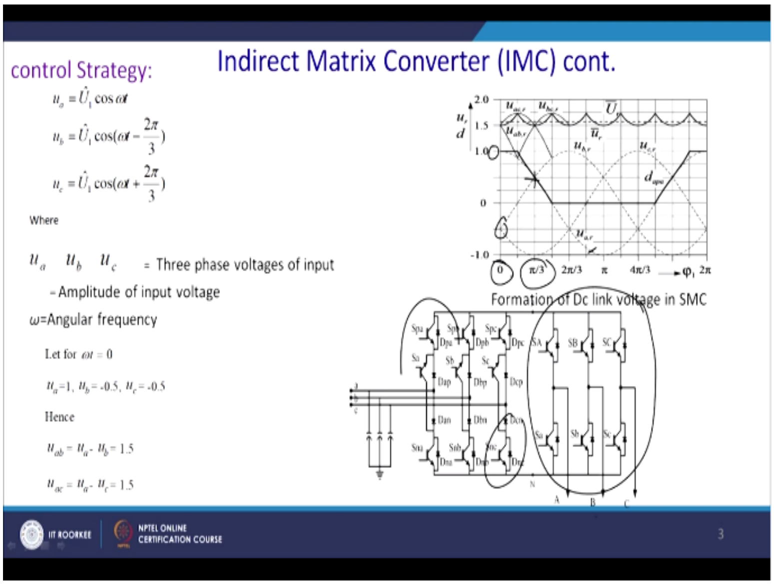

And now come to this point actually how actually it has been controlled. So generally you know inverter part is essentially a generally two-level inverter or the three-level inverter depending on the actual rating of the switches but you can consider a sparse matrix here with the reduced switches. So we will consider actually ua is actually instead of sin cos, so actually that is the most positive phase at the zero instant.

And accordingly ub will be 120 degree phase shifted and uc will be 240 degree phase shifted. So at the beginning at the instant you now you can see that this is basically this dotted line you know actually this dotted line is essentially is the ua and you will be switching in such a manner that maximum DC will be coming to this fictitious Dc bus voltage. So what will happen you know and you can see that and at that time C is the most negative phase.

And thus what will happen you know you will get a ripple that so you will and you will actually conduct the phase A, upper leg of the phase A of these switches and lower leg of the phase C so that you get the voltage u ac, r. Similarly, you can see that this is basically after this interval after 30 degree interval after 60 degree interval at this point; B will be the most positive phase.

C continued to be the most negative phase, then you will be switching B and C, positive part of the B switches and negative part of the C switches. So you will get bc, r accordingly all the switching sequence will become ac, bc like that you are continued to get. So ua, ub, uc are the three-phase input voltages at the amplitude of having these are the amplitude and angular frequency omega and omega t=0.

You can see that actually it is a balanced (()) (03:26) system so actually summation of this three instantaneous voltage will give you zero and actually ua=1 and ub=-0.5 and uc=+0.5 and so you are here, basically this is 0.5- for b and 0.5- for c and a here will be 1. So essentially if you subtract -0.5 and 1 so you are going to get essentially the maximum voltage 1.5 time of the line voltages.

Then, C continued to be actually down and thus your voltage will increase and it will change at the point of actually 60 degree from actually zero crossing but here zero crossing start at a instant of pi/2.

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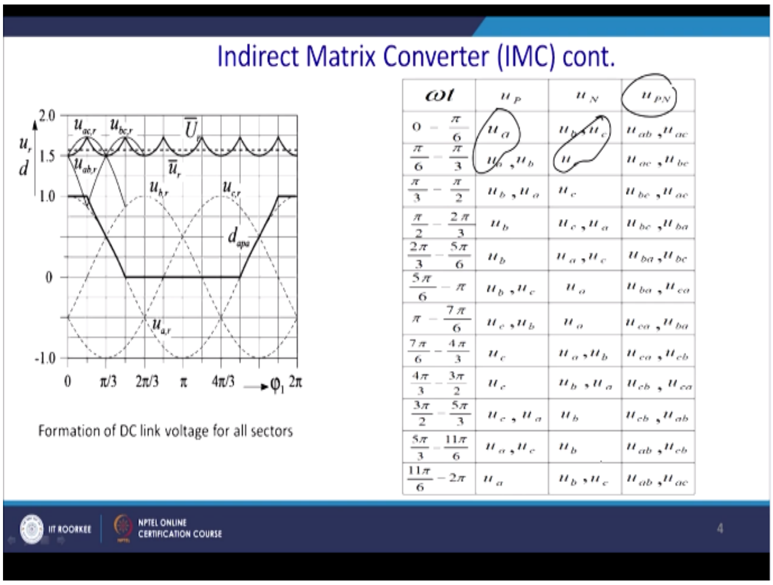

So these are the sequence you know how you will switch it on, you can see that so this is the upper leg and this is the lower leg. So at 0 to 60 degree you know upper leg ua will be switched on and there will be a changeover at 30 degree to b to c and thus actually PN voltage that is this the pole to neutral voltage will be ab and ac. Similarly, pi/6 to actually pi/3 you will have this sequence ua, ub and uN=uc and this will be the voltage.

So these are the sequential curve with the 30 degree interval of time. So it will be changeover every 60 degree. So ua will be there for the period of 60 degree. Similarly, uc will be there for the period of 60 degree. So automatically this switching pattern will take place. So and thus you get a maximum DC link voltage, fictitious DC link voltage in that manner.

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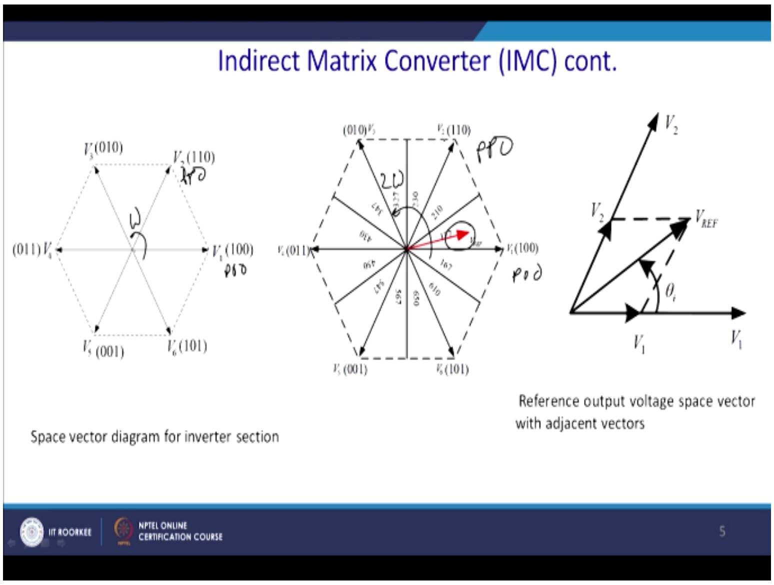

Now how you will generate? Let us consider that you have, we have discussed already that you are changing the frequency 25 hertz to 50 hertz or your actually 50 hertz to 100 hertz. So this is your input space vectors and where 110 what we discuss about POO or similarly to be POO. So this is basically PPO, similarly you have a two-level space vector and this will be mapped to the actually space vector which is rotating maybe the 2 omega or 3 omega.

If it is rotating at a speed omega, so what we required to do, we have to actually split these vectors in between and we are sure that basically if you want to generate some voltage here in this sector, same voltage will be actually generating here at the input at the output of this indirect matrix converter. So it will be the combination of the 1, 2, 7 where 1 is actually 100, 2 is 110 or in terms of the (()) (07:21) actually book actually it is POO, it is PPO.

So this and you will have this V1 and V2 and thus you got a V ref here. So let us see how you will generate this.

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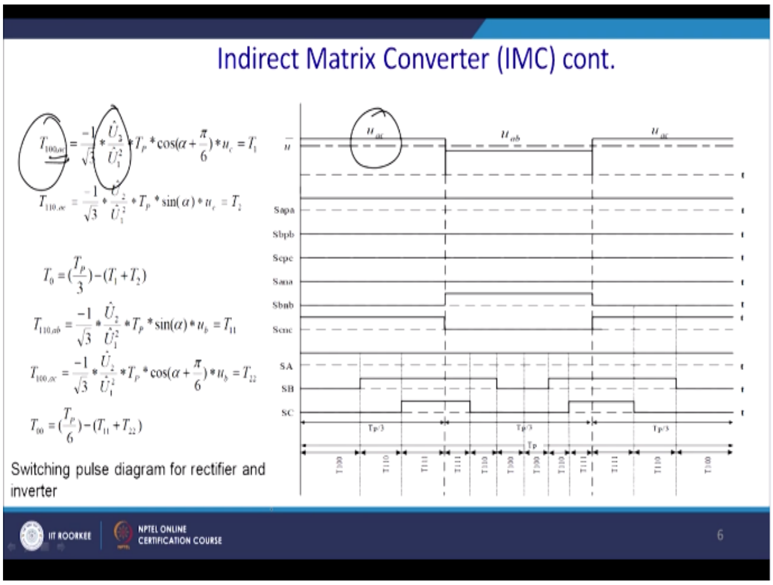

Now this is the switching logic and you have to calculate the same way you have calculated actually the time for the action of voltage vector V1, so that is for a1 that is -1/root 3 U2 this is basically the unit vector*Tp is the processing sign cos omega t*uc and this time essentially will be equal to T1. Basically why, you know this voltage applied here is AC and it is for the duration for 60 degree, for actually alpha+pi/6.

So for this reason, this is T1. Similarly, for T2 we will have to have a sin component and this should be -1/under root 3 this term Tp sin of alpha uc=T2. So you subtract T1 and T2 and you get the T0. First, of course you start with the voltage vector T110 thereafter actually it will be 100, thereafter you will have of course you have to apply the null vector at T0 that will be basically 111 that again you will apply 111, that again will apply 110, then 100, then 110, then again 111.

Again this sequence will be repeated, so here if you see that this is basically that uac so this will be the sequence to be followed for these three switches and thus you can generate these voltages in this configuration.

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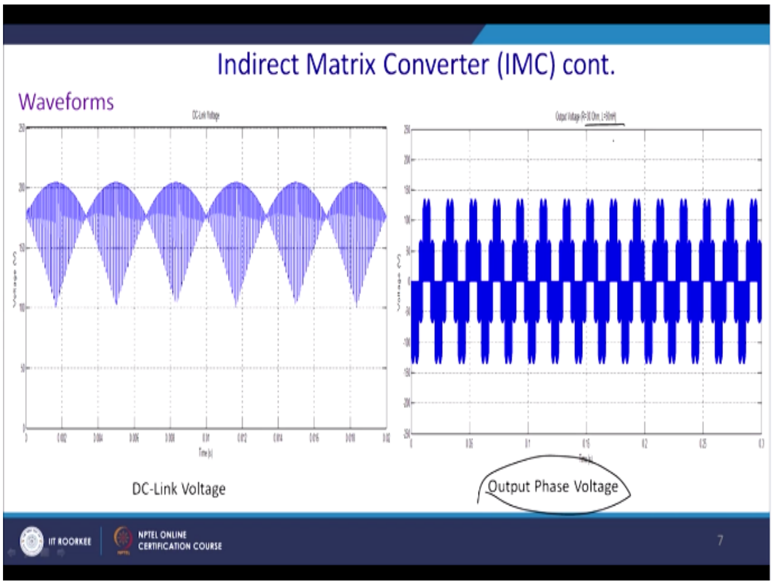

Now this is the DC link voltage you will get, the ripple DC you will get since there is no output voltage, no capacitor to filter it out or smooth out, you will get a ripple voltage every 60 degree interval. Ultimately, you can see that this interval so it will be around 60 degree and similarly this will be the phase output voltages which will be converted for actually for, this is basically the output simulation results, practical results can be shown later that is for the 30 ohm with the 50 hertz applications.

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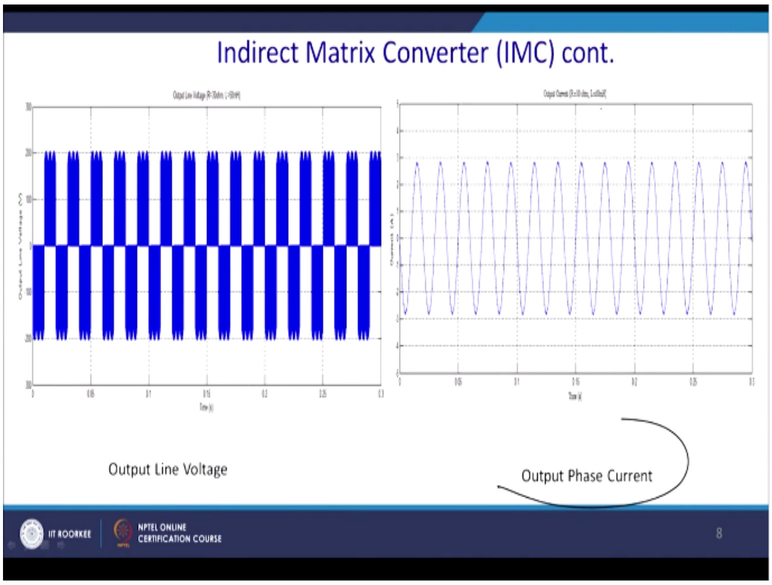

Now here this is the output line voltages and this is the output phase current and which you will find to be sinusoidal and ultimately it gives better results than the sine triangle PWM and THD is quite low for this actually filters.

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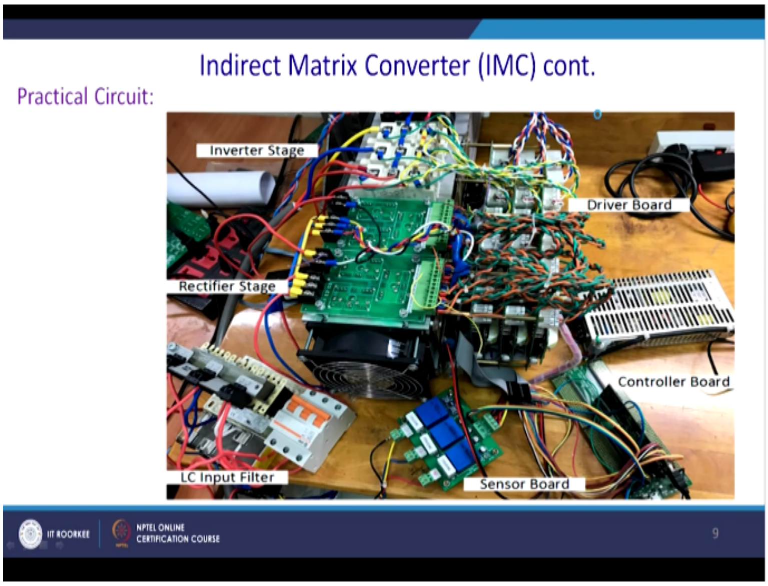

Now this is the hardware setup. We are making the practical hardwares on it and we shall show these results later. Now let us come to the one main challenge of this actually inverter topologies or AC to AC direct conversion. Problem is that your voltage, output voltage is reduced than your input voltage. So this is one of the biggest disadvantages to direct AC to AC conversion and to mitigate this problem you know for this reason we required to have some kind of boosting stage to boost up the voltage.

And this can be done and this can be incorporated into the directly AC to AC conversion. We have already discussed about that Z-source inverter and here in the Z-source inverter we have discussed in our class few classes ago.

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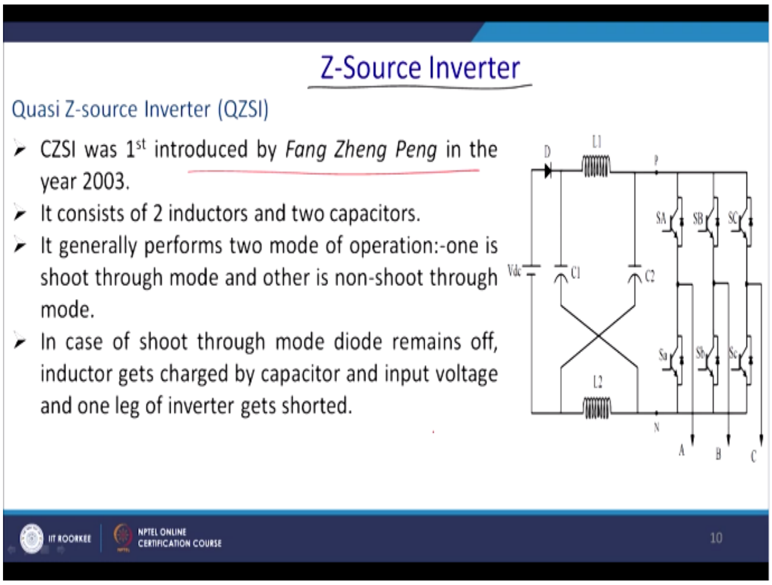

So it is introduced by the F. Z. Peng and this is once actually shorted, these two capacitors comes into the series, ultimately voltage becomes basically VC1+VC2 and you get a higher boosting effect. Can we have a same kind of concept incorporated in direct AC to AC conversion? So that is the challenge we can see.

So we know that actually it consists of the two inductor and the two capacitor and it generally performs two mode of operation, one is the shoot through mode that means when you actually shot the switches. Please refer to my lectures of the Z-source inverter and in case of the shoot through mode diode remains off and inductor gets charged by the capacitor and the input voltage and the one leg up of the inverter get shorted and thus boosting operation is achieved.

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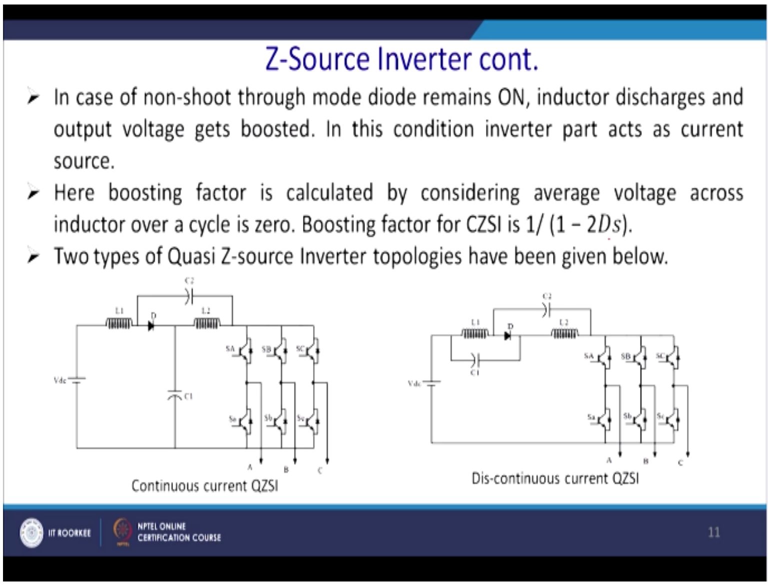

Now in case of the non-shoot through stage, the diode remains on and inductor discharges and the output voltage get boosted up and in this condition inverter part acts as a current source. Here boosting factor is calculated by considering the average voltage across the inductor over a cycle zero and boosting factor of actually this Z-source inverter is 1/1-2 Ds. So you can maximum actually give the 50% duty cycle, so otherwise there will be a instability.

So two types of Quasi Z-source inverters has been given below. This is one of the case of the Quasi Z-source inverter we had. Please refer to our discussions of the Z-source inverter. It is just the recapitulations, so there is a continuous mode of actually the Z-source inverter and

Quasi Z-source inverter and this is a discontinuous mode of Quasi Z-source inverter where inductor current is quite low.

And we prefer to actually have a discontinuous mode of Quasi Z-source inverter. Now this is the extension of the Quasi Z-source inverter that is called extended boost Z-source inverter. After Quasi Z-source inverter such as where actually focused on increasing the boosting factor further. So how can we actually boost this actually ratio.

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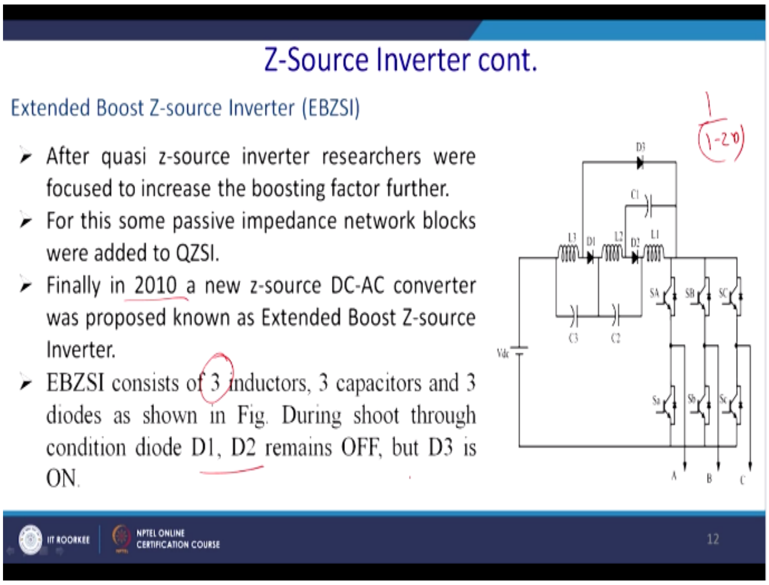

That is actually 1/1-2D, so it is limited to actually the some value. So this value is basically 0.5 and can we actually get it actually at a reduced value. For this some passive impedance network were added and you can see that instead of actually two inductors you have a three inductors and finally we can have another boosting effect and finally in 2010 a new DC to DC converters was proposed knows as extended Z-source inverter.

This extended Z-source inverter consist of the 3 inductors and the 3 capacitor and the 3 diodes and during shot through condition diode D1, D2 remains off but the diode D3 is forward biased and it is on and thus it pumps the continuous energy.

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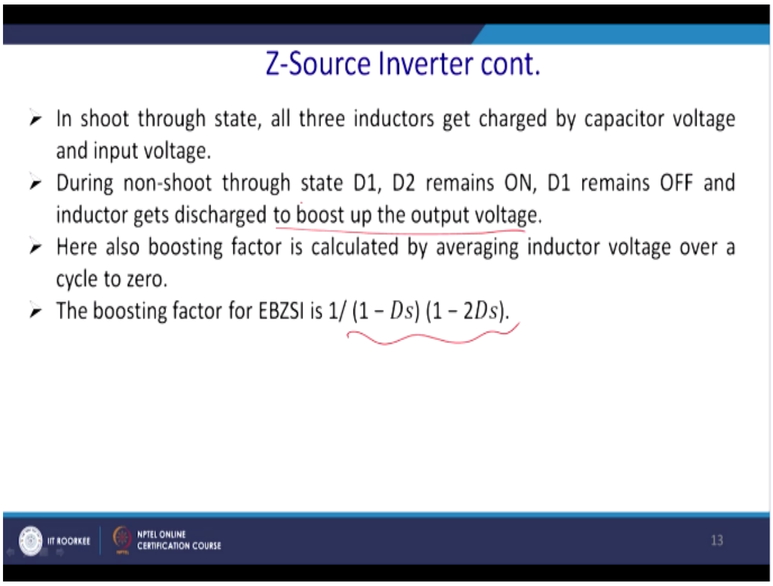

In shoot through state all the three inductors gets charged by the capacitors and during on no shoot through state, the diode D1, D2 remains on and D1 remains off and the inductor gets discharged to the boost out the output voltage and so overall boosting stage is been achieved is 1/1-D*1-2D. So huge boosting can be achieved with the help of this actually enhance boosting capacity.

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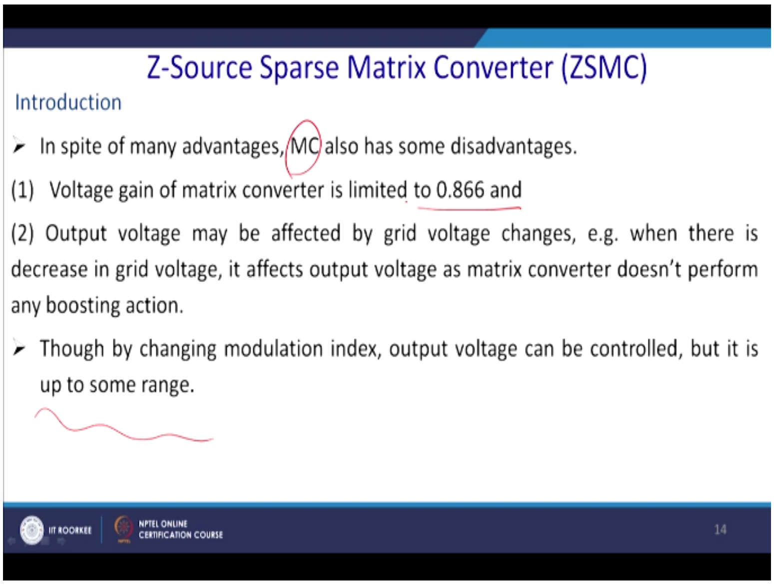

So let us incorporate that Z-source concept into the sparse matrix. So in spite of many advantages that is what I was saying this matrix converter also has some disadvantages. Voltage gain of the matrix converter is limited to 0.866, output voltage may be affected by the grid voltage changes when there is a decrease in the grid voltage and it affects the output voltage and the matrix converter does not perform the boosting action.

Though by changing the modulation index, output voltage can we controlled but it is up to some range and voltage gain of the matrix converter direct matrix converter is limited to 0.866. So that is the limitations of it.

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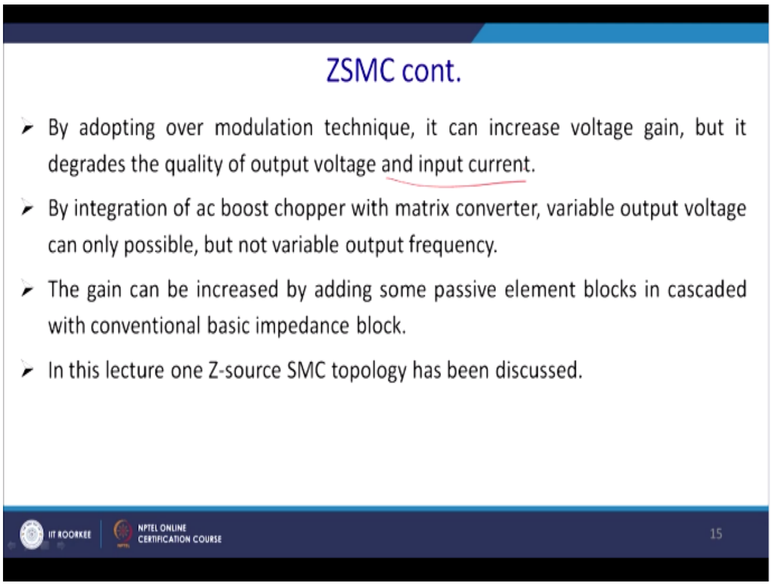

By adopting over modulation technique but it can increase the voltage gain likes you know third harmonic injection and all those technique can be applied here but it degrades the quality of the output voltage and the input current. So THD will be the causality there and also you do not get much of the boosting. By integration of the AC boost chopper with the matrix converter, variable output voltage can only possible but not variable frequency operation.

So it not allows the variable frequency operation, it can allow only actual fixed voltage operation. The gain is increased by adding some passive elements block in cascade with the conventional basic impedance network. In this lecture, one of the Z-source SMC topology has been discussed for the lack of time.

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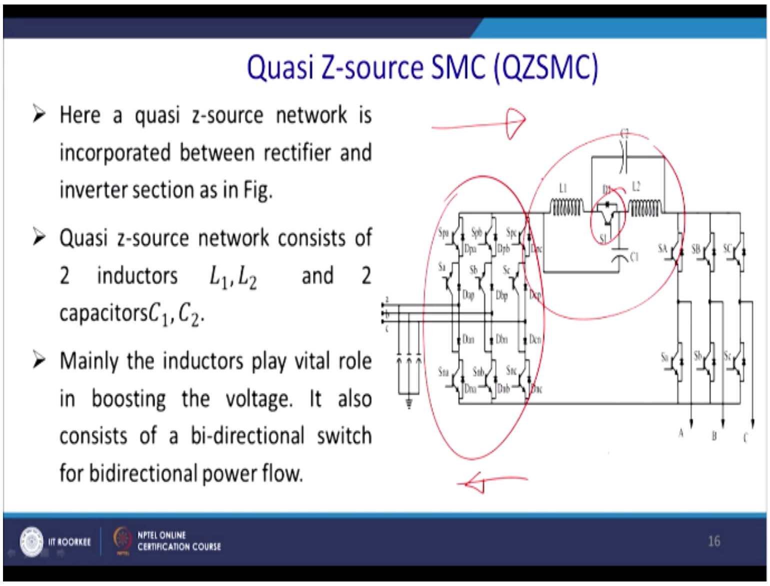

So this is actually a topology, it is actually this part is already we have discussed, this is the DC part, this is the converter part and this is the inverter part. In between, you have added this actually the boosting network and here you can see that with this not only you can actually control the frequency but also can control, of course you can actually buck it by changing the modulation index.

And this part of the circuit can help you also boost it thus it is a basically an idealized solid state transformer. So it is fine it will be highly used in future with a penetration of the silicon carbide based device, we shall use this device, this topology and the variant topology as actually solid phase transformer, it will be compact, it will be a very useful thing and it will be less bulky and you have a lot of other advantages.

Let us see how does it work. It is a Quasi Z-source network is incorporated between the rectifier and the inverter as shown in the figure. The Quasi Z-source network consists of the two inductors L1, L2 and the two capacitors C1, C2, in between there will be a shoot through state. Mainly, the inductor plays a vital role in boosting the voltage. It also consists of a bidirectional switch and the bidirectional power flow.

So sometime we may not actually but you can use for regenerative braking also, it is not that power flow is this, it can be also in this way. So here we require sometime for bidirectional flow. So this is the configuration, so you have a input state intact as working to generate the DC link voltage and you will apply the shoot through into your actually inversion stage.

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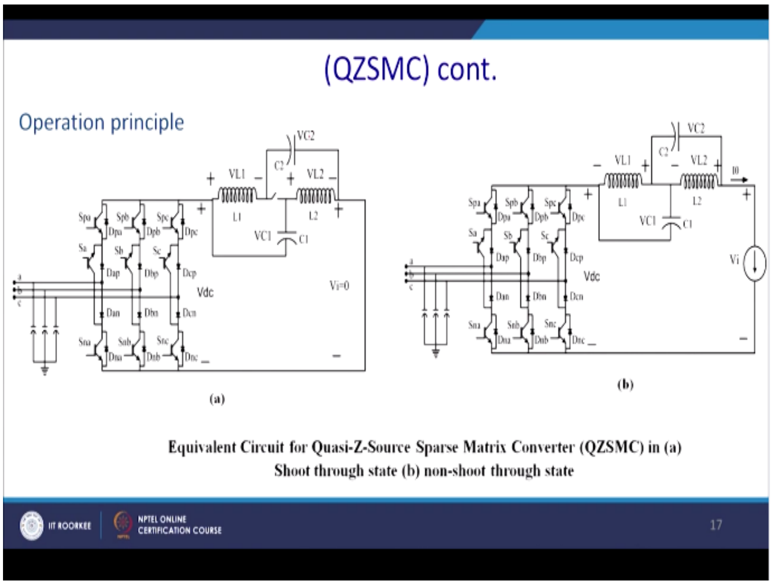

And thus what will happen, you will be boosting a voltage VC1 and VC2 above your Vdc and thus what will happen, VC1 and VC2 will come and it will add up this DC link voltage and you will get the extra DC link voltage to be converted into the extra AC side line voltages. This is basically the shoot through state and this is a non-shoot through state. We will consider that once CSI is connected.

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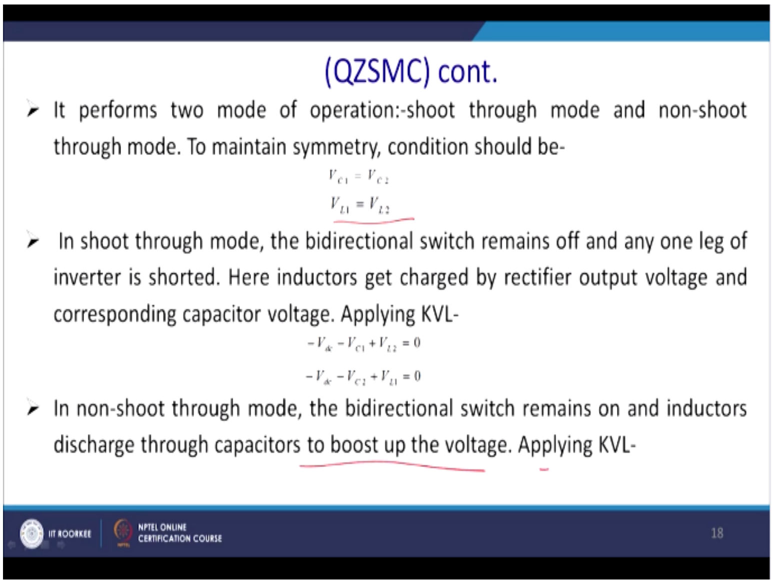

So it performs the two mode of operation, shoot through mode and the non-shoot through mode to maintain the symmetrical condition VC1=VC2 and VL1 will be VL2. In shoot-through mode, the bidirectional switch remains of and any one leg of the inverter is shorted. Here inductor gets charged by the rectifier output voltage and corresponding the capacitor voltage and if we apply KVL-Vdc-VC1+VL2=0 or –Vdc-VC2+VL1=0.

In non-shoot through mode, this bidirectional switch remains on and the inductor discharges to the capacitor to boost up the voltage.

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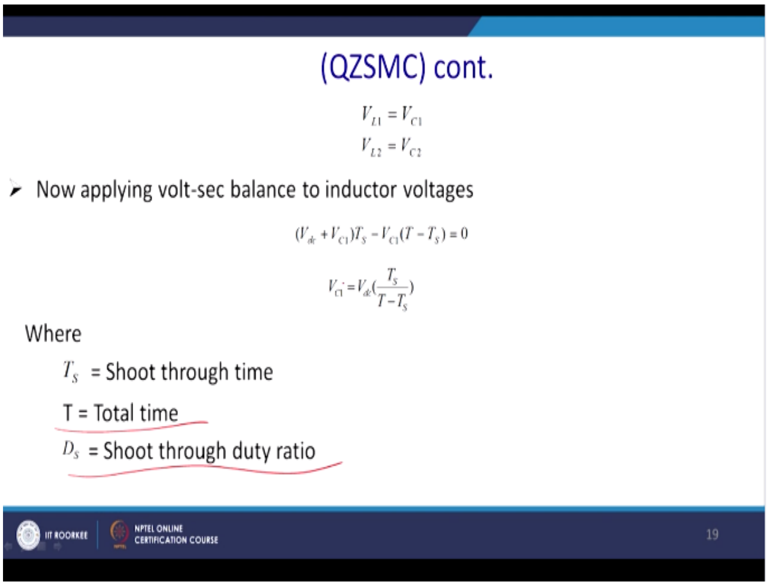

And by applying KVL what essentially will get, VL1=VC1 and VL2=VC2 and thus what happen you know so you can equate this two equations. Vdc+VC1*Ts-VC1 T-Ts=0 and thus VC1=Vdc Ts/T-Ts where Ts is the shoot through state and T is the total time and Ds the shoot through ratio. In that way, you can boost up the VC1.

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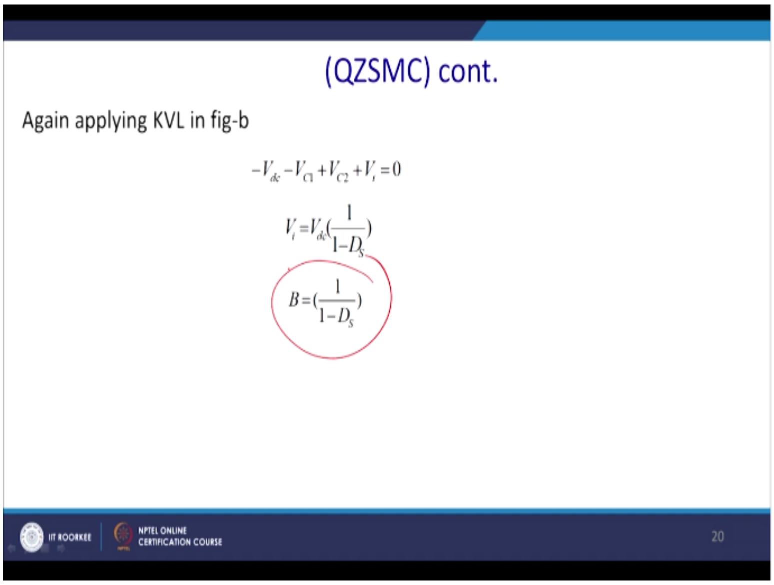

So again applying KVL so you can find it out that basically the overall gain is just in case of a simple boost simple Z-source network that is 1/1-Ds where Ds stands for the shoot through ratio that is shoot through by the total time period. Now let us switch over the topic, so it require little conclusion. Actually, we have discussed the direct AC to AC conversion, we have started with the bulky cycloconverters that are gradually move to a sleek devices like matrix converter and we have seen the problem of the matrix converter.

Then, from this matrix converter we have come down to the actually direct matrix converter to indirect matrix converter and from the indirect matrix converter we have actually derived different topologies and also actually made the challenge of the actually boosting of the voltage. Gradually actually these days are not far behind when we will see that instead of this actually all these copper transformer these are replaced by the silicon carbide based transformer.

And will see that very sleek and bulky instead of this bulky, heavy transformer, will see that a very compact sleek transformer and it is quite useful where weight is a major concern like aircraft, etc. Now let us switch over to another important topic that is basically the power quality. Power quality is actually issue popped up due to the advancement of this power electronics.

Because as long as voltage and current was sinusoidal with the linear load there was no problem and there is a problem with the power factor and that can be minimized with the reverse kind of load by a wall compensator. Now due to the advent of the power electronics and its rampant uses like adjustable speed drive and other applications power what we get it is being virtually is polluted.

Now I as a consumer I want actually a clean power from the utility but unfortunately due to penetration of the power electronics, power quality get degraded. So our now discussions will be focused on the power quality. So let us define power quality, what is it.

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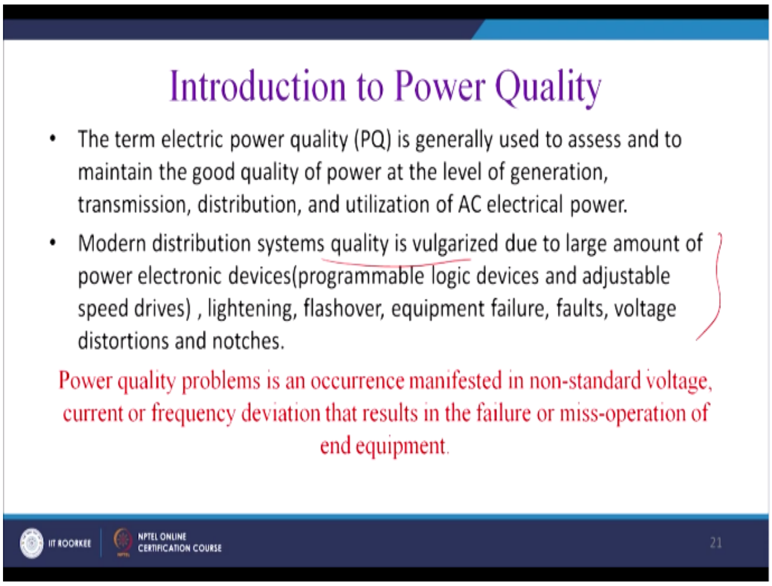

The term electric power quality is generally used to assess and to maintain the good quality power at the level of generation, transmission, distributions and utilizations of AC electrical power. Modern distribution system, the power quality is vulgarized due to the large amount of the power electronics devices but unfortunately we wanted to have a actually the solution through the power electronics only.

The programmable logic drives, adjustable speed drive, lightning, flashover, equipment failure, faults, voltage, distortion and notches, these are basically spoils or decreases the power quality. Power quality problem is an occurrence manifested in nonstandard voltage and current and frequency. If there is sudden swell and sag or voltage, current and the frequency deviation, that results in failure of the missed operation of the main equipments.

So this is a major challenge nowadays, you can see the different kind of waveforms. All of a sudden, notches has come. This is basically a transient phenomena.

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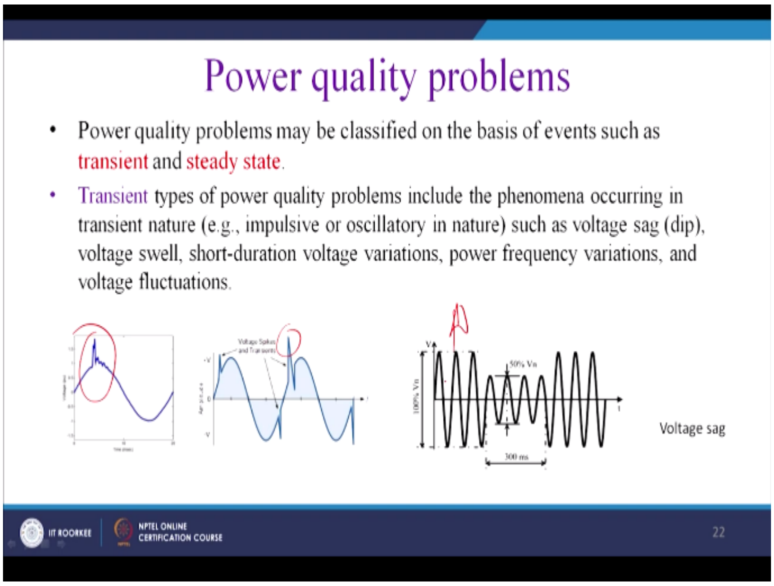

If notches continue in cycles then we have to consider the spikes. Now all of a sudden, voltages has sagged half of the voltage almost. So this is only basically the voltage sag. So power quality problem may be classified on the basis of the events such as transient, occurrence is all of a sudden thereafter it is okay or in a steady state. This transient type power quality problem includes the phenomena occurring in the transient nature are impulsive and oscillatory nature such as voltage dip, voltage swell.

Voltage swell means actually voltage will go off, short duration voltage variations, power frequency variations and the voltage fluctuations.

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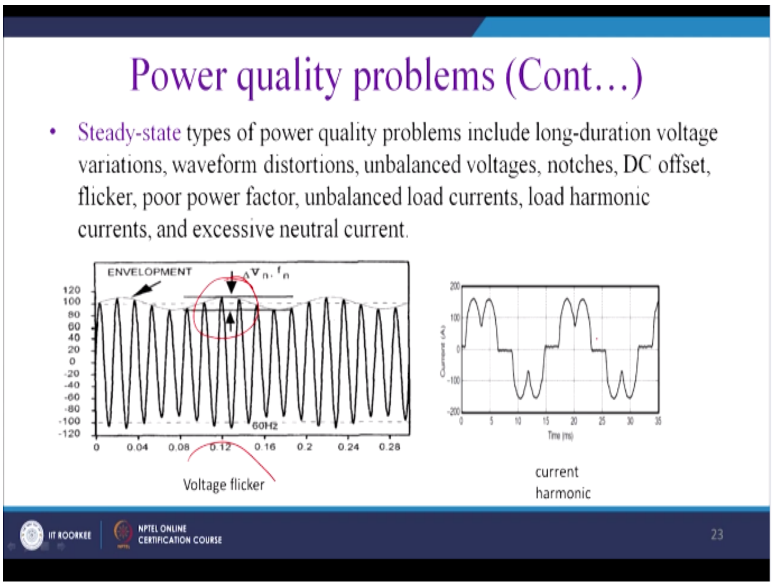

So this is the voltage flicker. Now steady state, the types of the power quality problems include the long duration voltage variation, waveform distortion, unbalanced voltages, notches, DC offset, flickers, poor power factor, unbalanced load current, load harmonics currents and excess neutral current. So you will get all and this is basically the voltage flickers, all of a sudden it will flicker and we can see that with these 50 years, there has been a low frequency is being superimposed.

And due to that it may actually cause lot of damage into the power system. It is very difficult to mitigate this current harmonics and this is actually a typical case of three-phase direct bridge rectifier fitting in RL load and you can see that voltage is far from sinusoid and you get a distorted current. This is a current harmonics.

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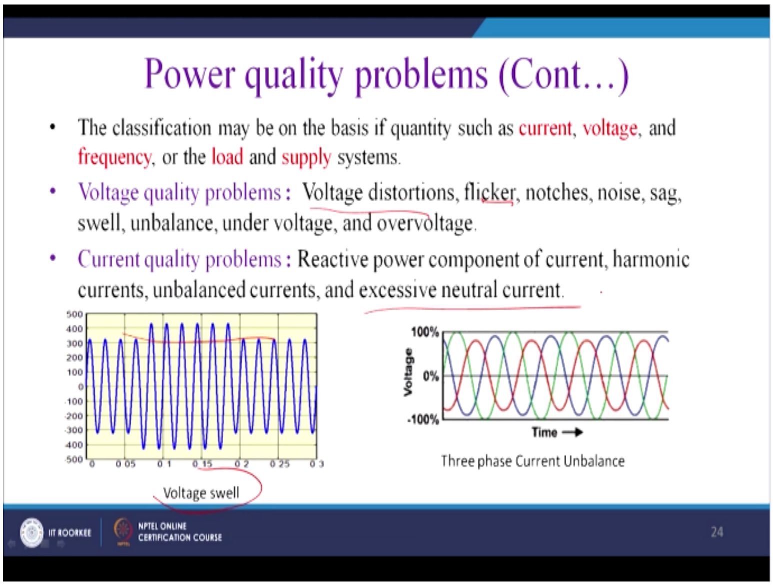

Now this is the voltage swell all of a sudden time and this is the unbalanced where one of the phases is basically having more current than two of the other phases. The classification maybe on the basis of the current voltage and the frequency or the load and supply system. Voltage quality problem that is voltage distortion, flickers we have shown it, notches, noise, sag, swell, unbalance, under voltage, overvoltage.

These are the categories of the power quality and current quality problem, the reactive power components of current harmonics, unbalanced current and excessive neutral current. These are power quality problems related to current.

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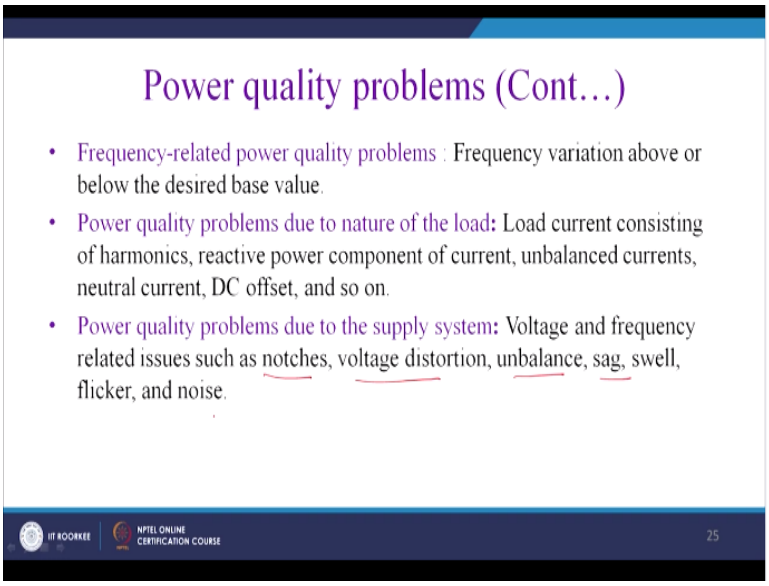

Now frequency related problem that is the power quality problem, frequency variation above or below the desired base value. We have a shifting and the power quality problem due to the nature of the load that is from if it is the nonlinear load, this problem arises. Load current consisting of the harmonics and the reactive component of the current, unbalanced current, neutral current and DC offset and so on.

And power quality problems due to the supply of the system, voltage and frequency related issues such as notches, voltage distortion, unbalance, sag, swell, flickers, noise all those things we have discussed. Now thank you for your attention. We shall continue to power quality in our next class. Thank you.