Power Quality

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PFC-Bridgeless buck boost Converters (Isolated Configurations)
Lecture - 34
Improved Power Quality Converters-AC-DC Buck-Boost Converters (Contd.)

Welcome to the course on Power Quality. So, today we will discuss Power Factor Corrected Bridgeless Buck Boost Converters with Isolated Configurations.

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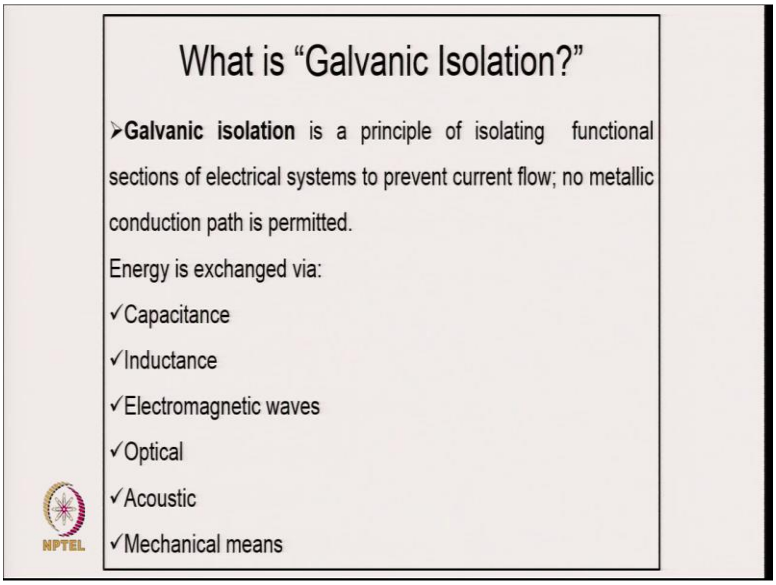

Why we require the isolation? The Galvanic isolation is a principle of isolating functional sections of electrical system to prevent current flow; no metallic conduction path is permitted. So, energy is exchanged via capacitance, inductance, electromagnetic wave, optical wave, acoustic wave or mechanical means.

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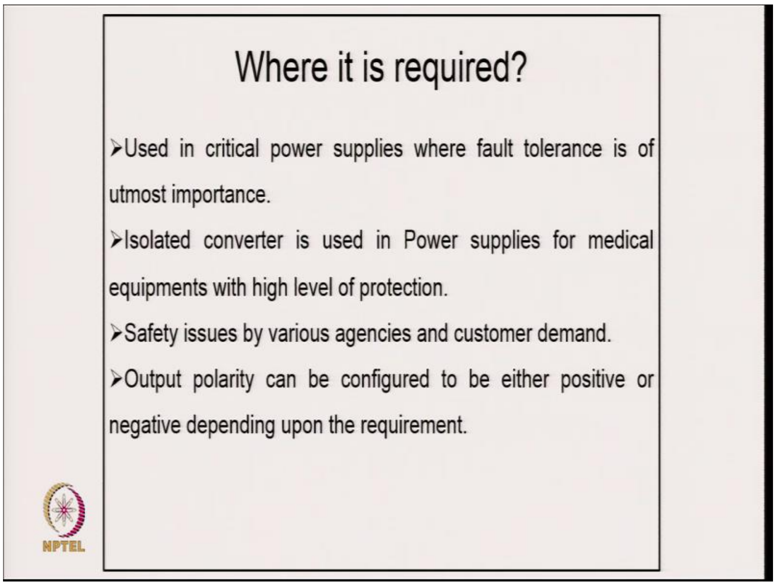

Where and why, it is required? Or in which applications we require?

It is used in critical power supply where fault tolerance is at most important; an isolated converter is used in power supply for medical equipment with the high level of protection and safety issues for various agencies and customer demand.

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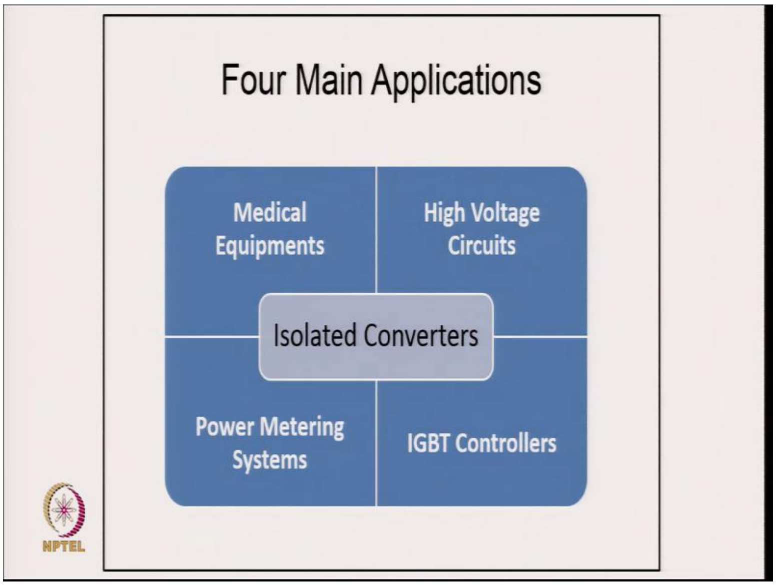

The four major applications are medical equipment, high voltage circuits, power metering systems and IGBT Controllers.

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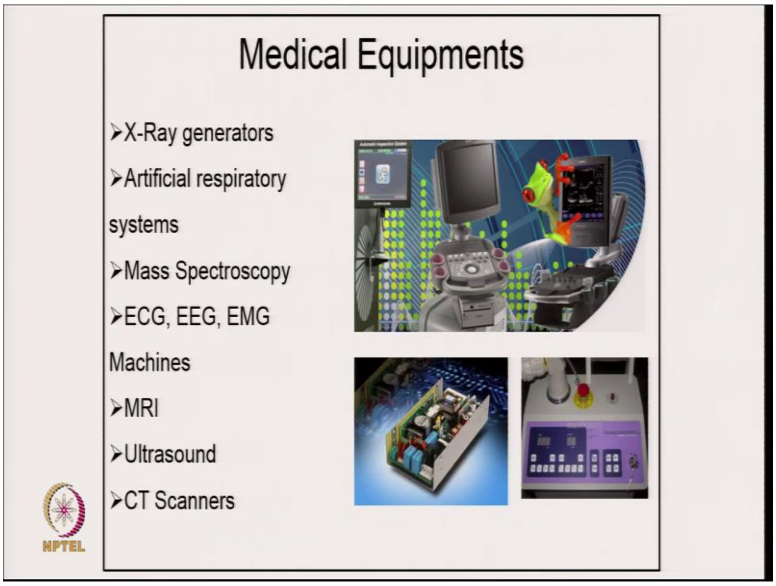

So, in the medical equipments, we use in x-ray generator, artificial respiratory system, mass spectroscopy, ECG, EEG, EMG machines and MRI machines, Ultrasound and CT scanners.

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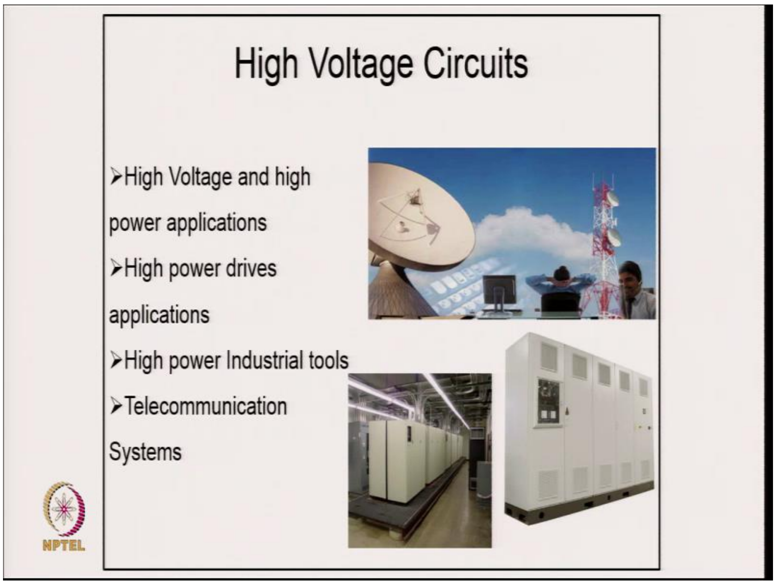

In a high voltage circuit, we need for high voltage and high-power applications, high power drive applications, high power industrial tools and telecommunication systems. So, these are some of the applications, where we use typically power factor corrected isolated DC-DC converter.

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Another set of applications is power metering systems.

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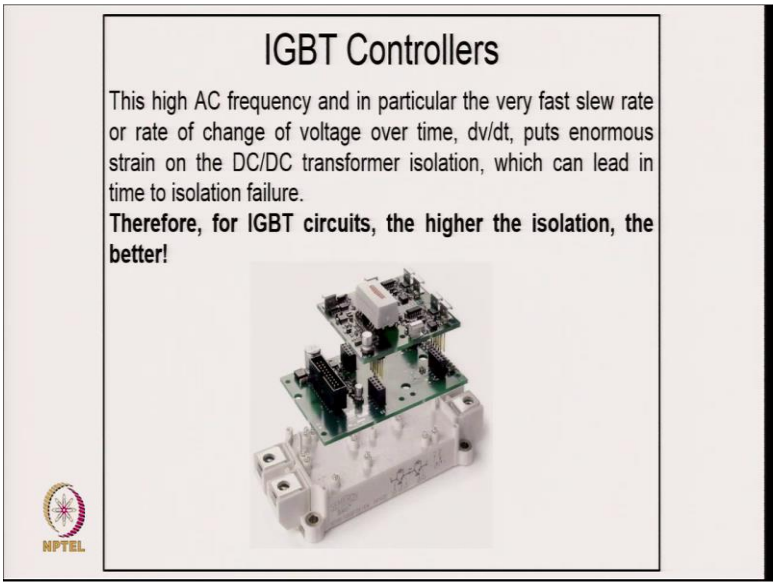

And another set is IGBT controllers. In such applications, very fast slew rate or rate of change of voltage over the time, i.e., dv/dt puts enormous strain on the DC-DC transformer isolation which can lead to isolation failure. Therefore, for IGBT circuits, the higher the isolation it is considered a better one.

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An emergent solution which is coming up is in welding machines. The high frequency welding machine require high current requirement (80 A – 12 kA) and utilizes high frequency transformer for the reduced size and reduced weight and reduced losses.

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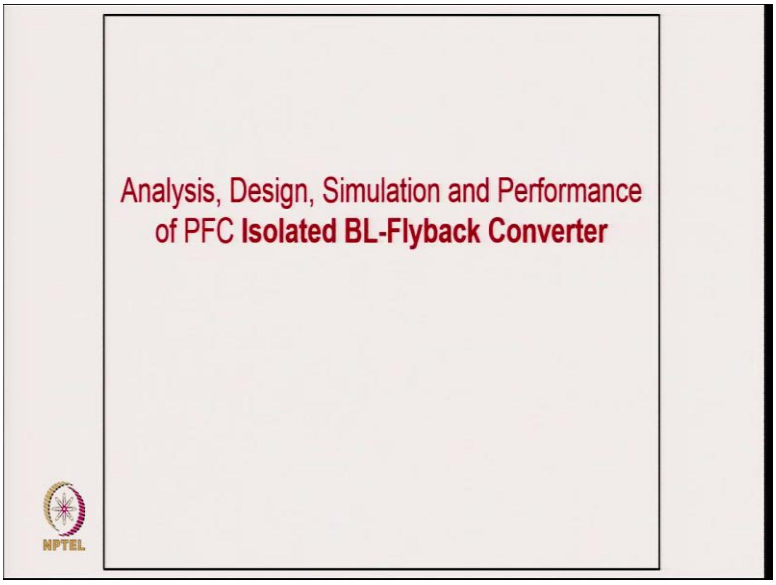

So, coming to the analysis, design, simulation, and performance of power factor corrected isolated bridgeless flyback converter.

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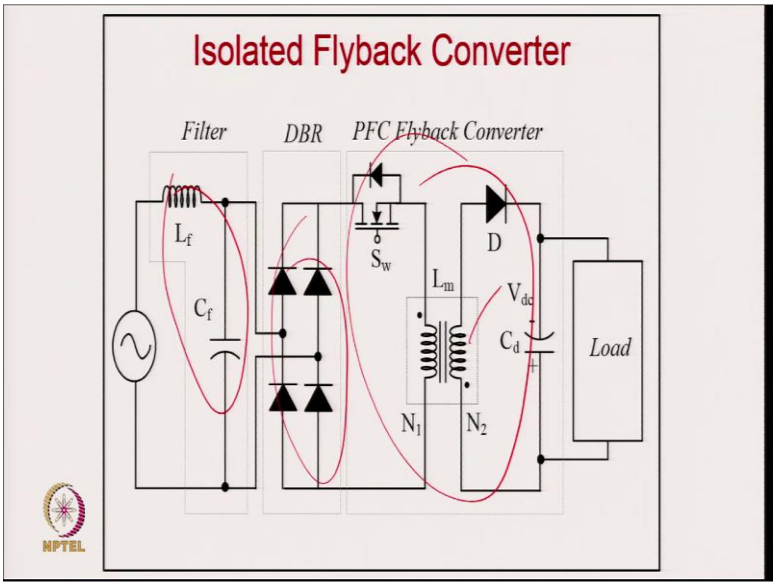

In conventional bridge-based flyback configuration, we will have an EMI filter, a diode bridge rectifier circuit, and of course, a power factor corrected flyback converter which can operate in discontinuous or continuous conduction mode. For discontinuous conduction mode we have to design flyback transformer's magnetizing inductance in discontinuous current mode. Otherwise, if you want typically CCM operation, then we need to design accordingly.

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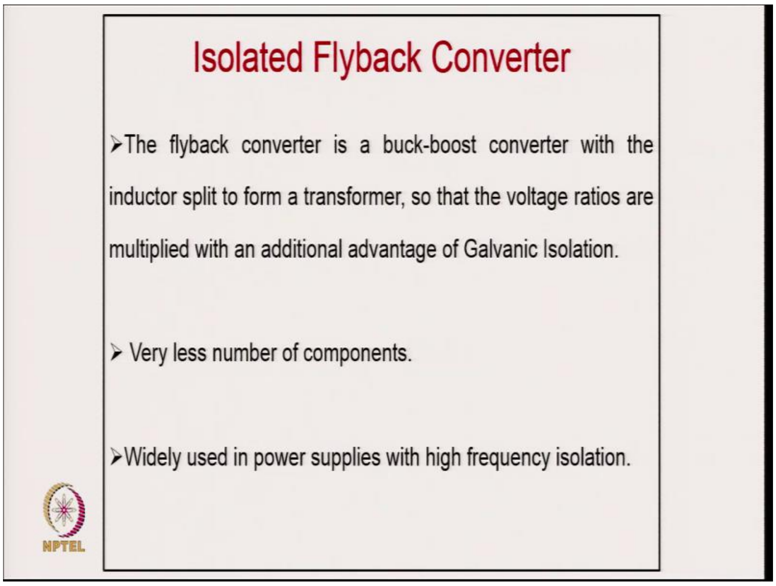

The flyback converter is a buck boost converter with the split inductor to form a transformer. So, the voltage ratio is maintained with the additional advantage of galvanic isolation and with very a smaller number of components. Such converters are widely used in power supply with the high frequency isolation over a wide range of power applications.

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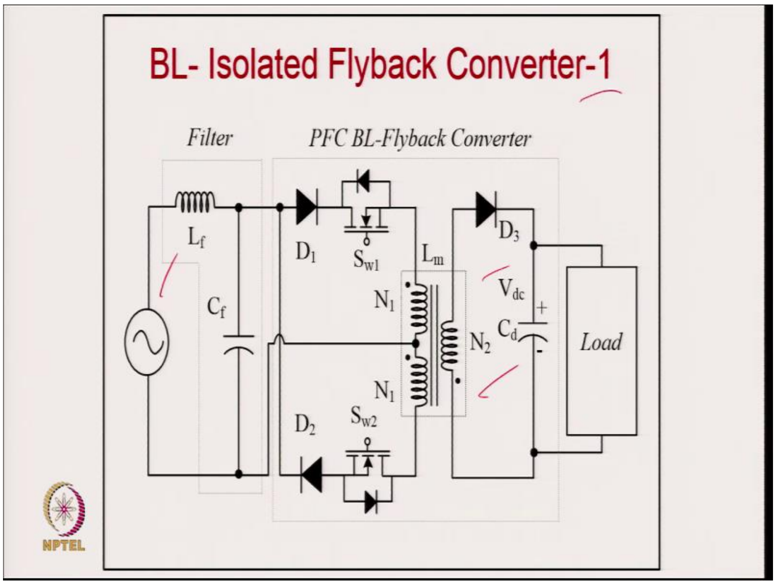

The bridgeless version of the flyback converter is shown here. In the bridgeless version the diode bridge is partially eliminated, of course, on the cost of couple of MOSFETs. The secondary circuit remains same, it may be multiple output also. The elimination of the diode bridge certainly enhances the efficiency up to some extent.

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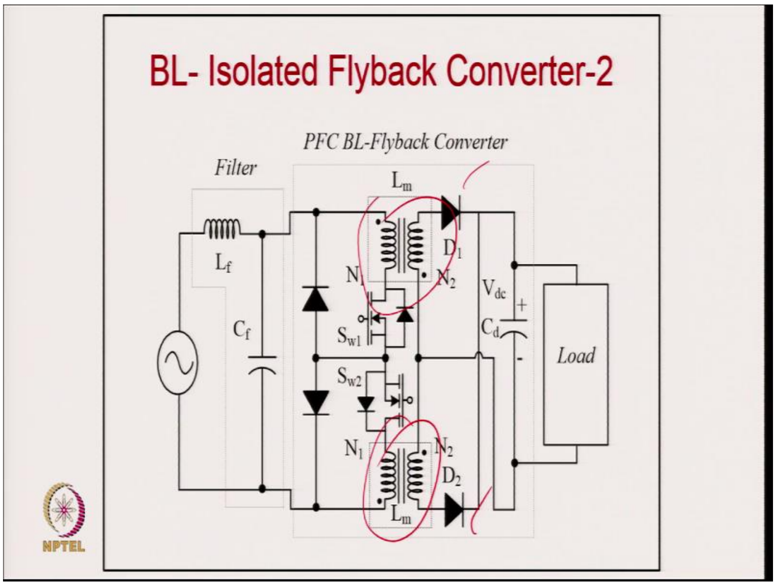

And this is the second circuit configuration which can be for little higher power. Because, this converter has two different circuits one for positive half cycle, another for negative half cycle with two separate transformers.

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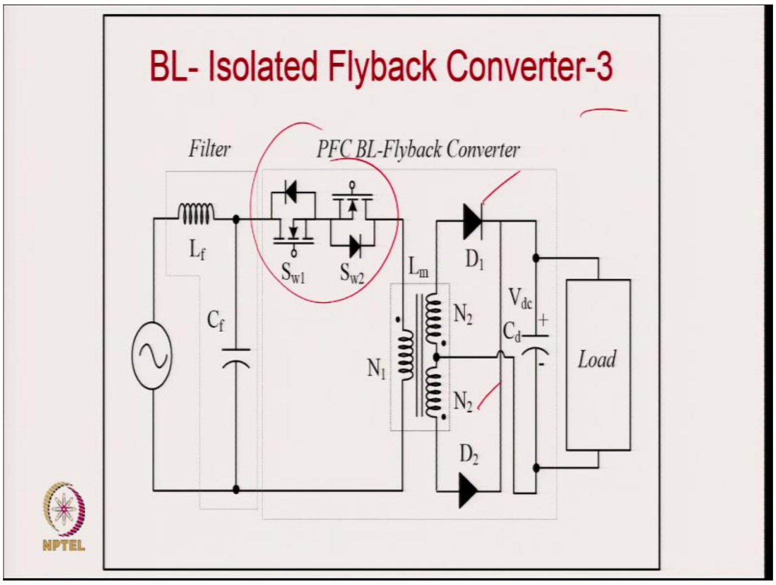

And this is the 3rd version of the bridgeless isolated flyback converter. Of course, we are using 2 devices in back-to-back manner, but we have completely eliminated the diode rectifier. In this, one MOSFET conduct for positive half cycle, and another conduct for negative half cycle. Then, in the secondary side, we have push-pull like configuration.

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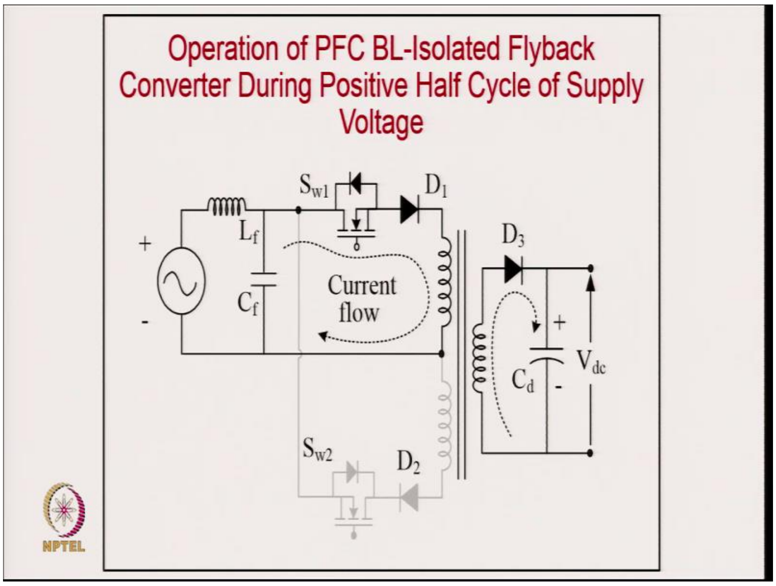

This is the operation of power factor corrected bridgeless isolated converter during positive half cycle.

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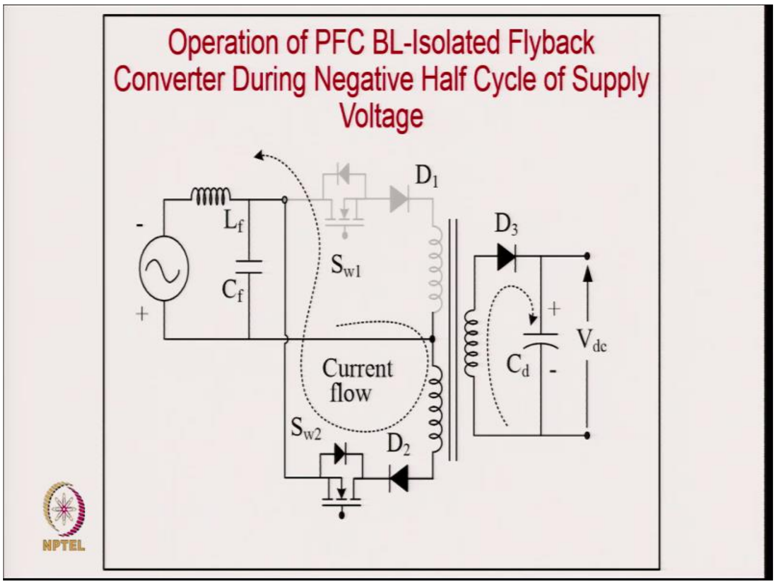

And this is the equivalent circuit for negative half cycle, the current flow path is shown by the dotted arrow.

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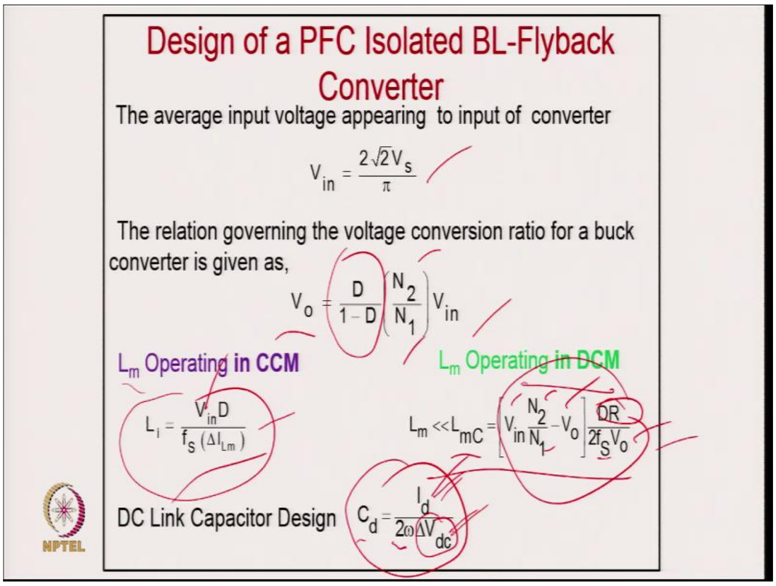

These are the design equations for the bridgeless isolated flyback converter topology under both continuous and discontinuous conduction mode.

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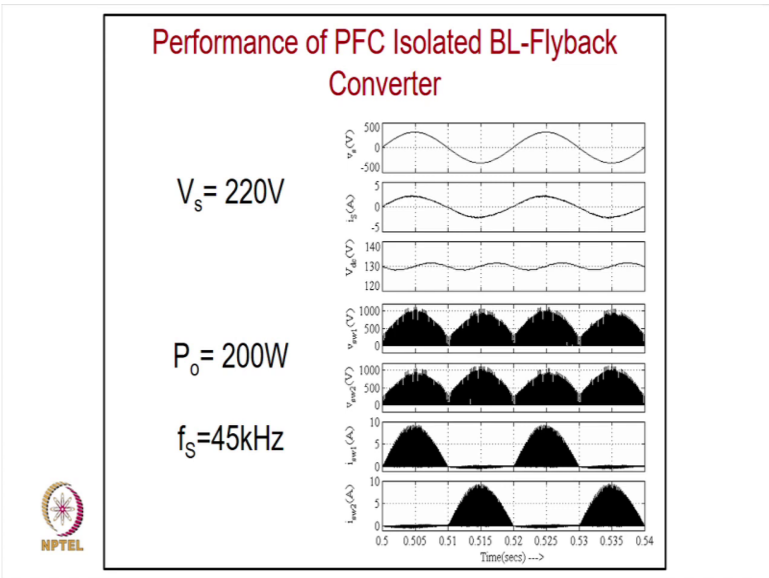

This is a typical example at 200 W and 45 kHz. You can clearly see, at supply voltage of 220, the supply current remains in phase with the supply voltage and the total harmonics distortion also remain negligible in this case. Further, the DC link voltage, switch voltage, and switch current are also given.

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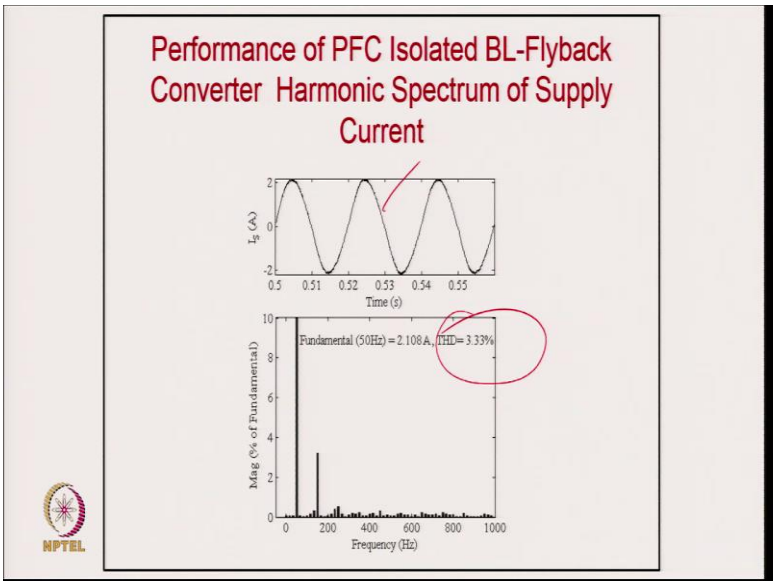

This is the harmonic spectrum of the supply current, as seen, the THD remains quite good, i.e., 3.3% for this power factor corrected isolated bridgeless flyback converter.

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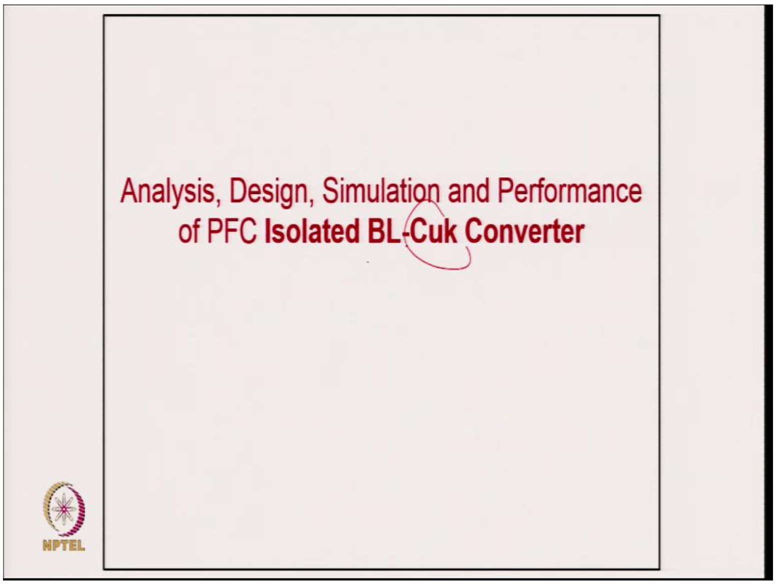

Now, coming to analysis, design, simulation and performance of power factor corrected isolated bridgeless Cuk converter.

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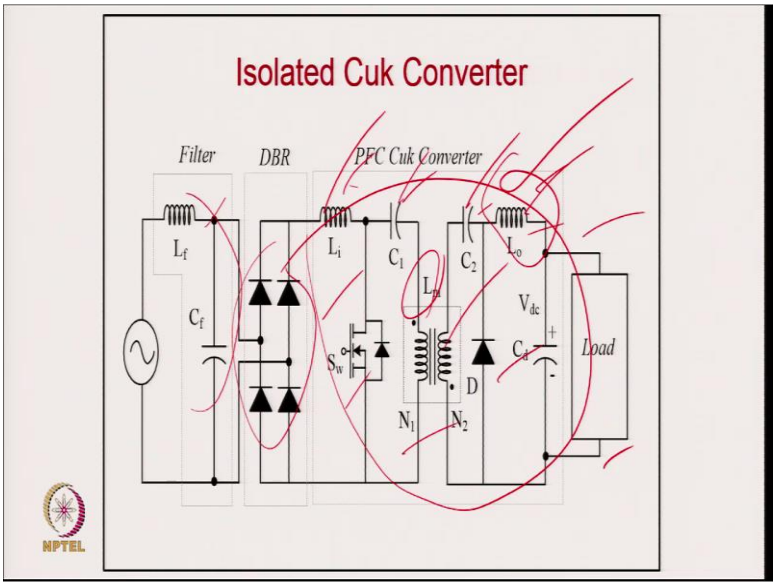

So, this is typically isolated PFC Cuk converter. This converter has an EMI filter, a diode bridge rectifier, and then an isolated Cuk converter. We can design this converter in many ways because there are 5 energy storage elements, i.e., input inductor, output inductor, energy transfer capacitors on primary side energy and secondary side, and the magnetizing inductance of isolation transformer.

This converter is very interesting because of the capacitor presence in input and output of transformer, and therefore, the transformer will work ideally even with the operating with a single device. Since there are 5 energy storage devices in this converter, therefore, you can have 32 designs for this converter. Out of 32 designs, 1 is the continuous conduction mode design, where, all the energy storage elements are designed in continuous conduction mode. Corresponding to CCM design, you need to sense the input voltage and input current along with the output voltage. But for the discontinuous conduction mode, you will have 31 design options. You have to select which one design is the best. We look into all the design and we found that the best design is corresponding to output inductor discontinuous conduction mode while all other remain in CCM operation. If you design input inductor in discontinuous mode, the size of the EMI filter increases. If you design capacitors into discontinuous voltage mode, then the voltage stress goes multifold across semiconductor devices.

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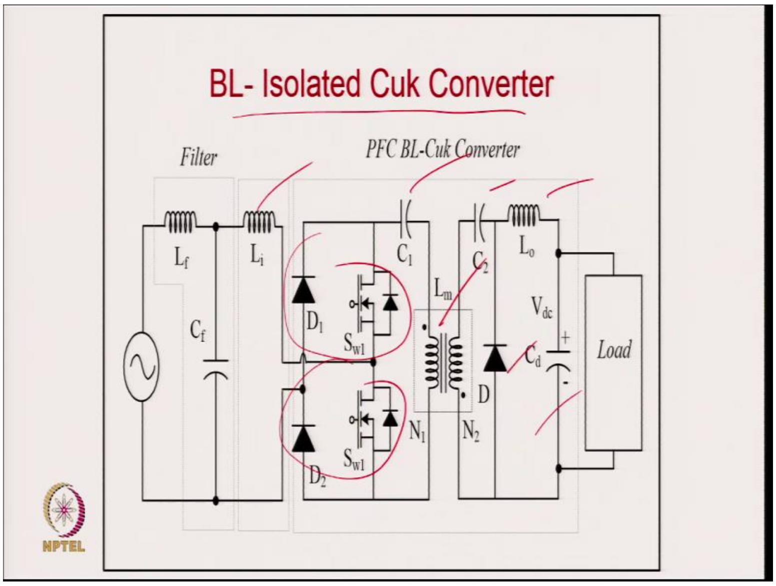

Well, this is the first version of the bridgeless isolated Cuk converter. In this, you have additional 1 diode, and 1 MOSFET, but you are able to get rid off with the diode bridge rectifier which reduces the losses in this converter.

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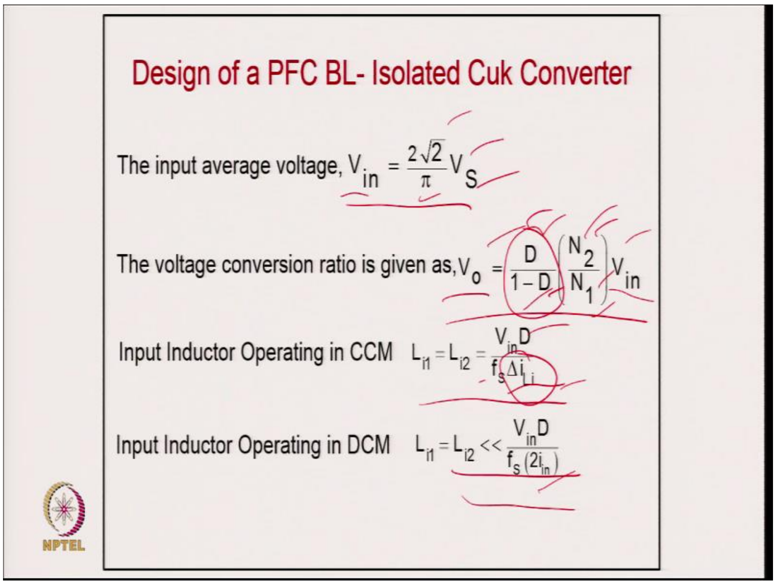

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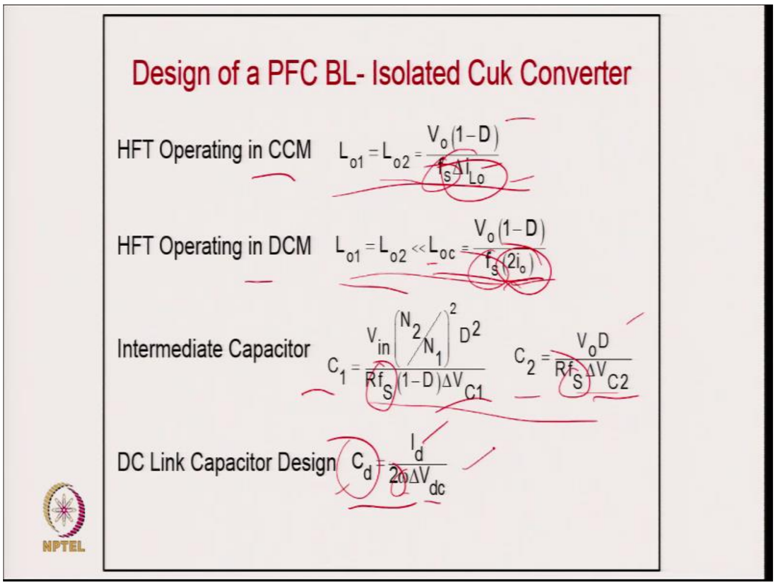

And, these are the design equations for the isolated bridgeless Cuk IPQCs. Notably, we generally prefer to design this converter at 0.5 duty cycle, to operate transformer in ideal manner.

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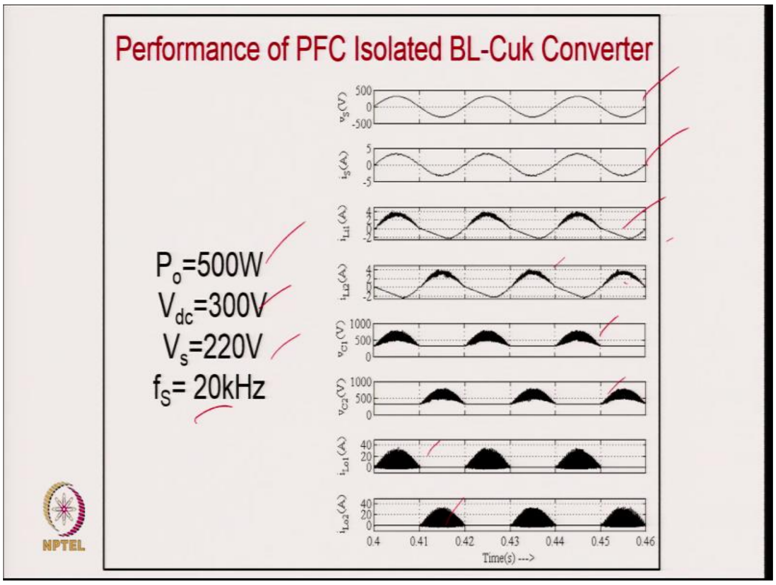

Now, coming to the case study, for 500 W with the output DC voltage of 300 V and the supply voltage of 220 V and at 20 kHz, these are the typical waveforms. Where, the output inductors are designed for discontinuous mode operation. The supply voltage and supply current remain in phase. The input inductor currents and capacitor voltages remain continuous. But, you can see, the output inductor current is in discontinuous mode.

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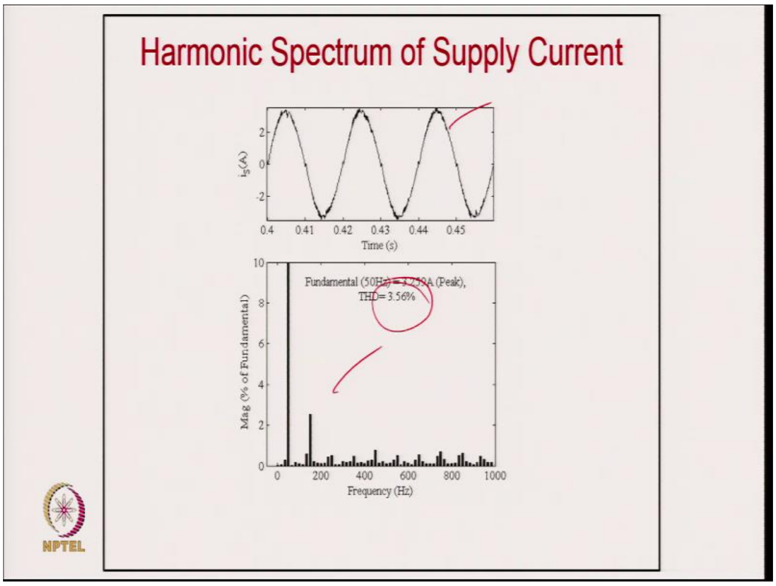

This is the supply current waveform and the THD. As per the harmonic’s spectrum of supply current, the THD is 3.56 %.

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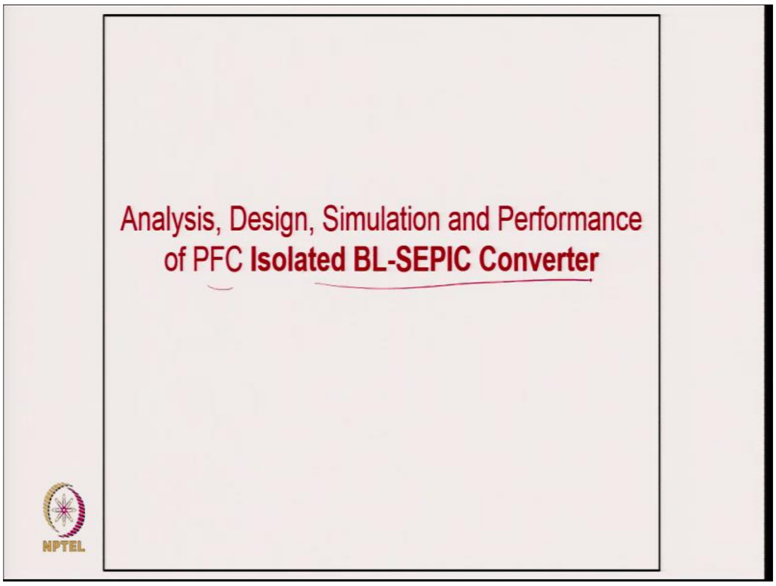

Now, coming to the analysis, design, simulation and performance of power factor corrected isolated bridgeless SEPIC converter.

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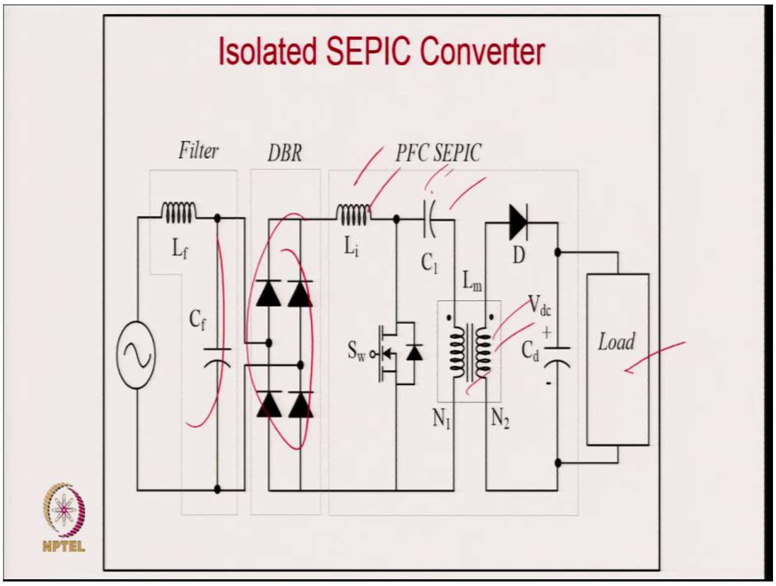

Well, this is the typical circuit of isolated SEPIC IPQC. This converter has an EMI filter, a diode rectifier and an isolated SEPIC IPQC. Here, we have 3 components, i.e., input inductor, intermediate capacitor and transformer magnetizing inductance, so, you can have total 8 design options, one for continuous conduction mode, i.e., all 3 components remain continuous. But if you are designing any one component either input inductor current, magnetizing inductance current or capacitor voltage, in discontinuous, then you have 7 design options.

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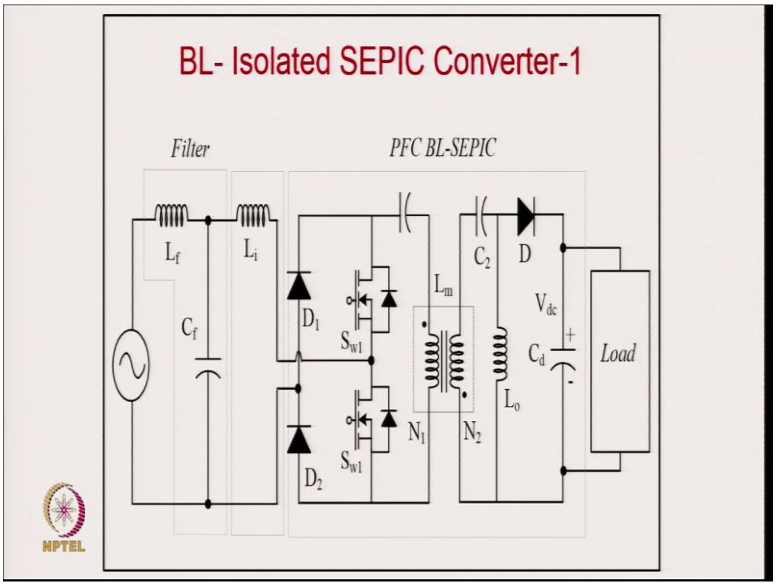

And this is the bridgeless version of isolated SEPIC IPQCs.

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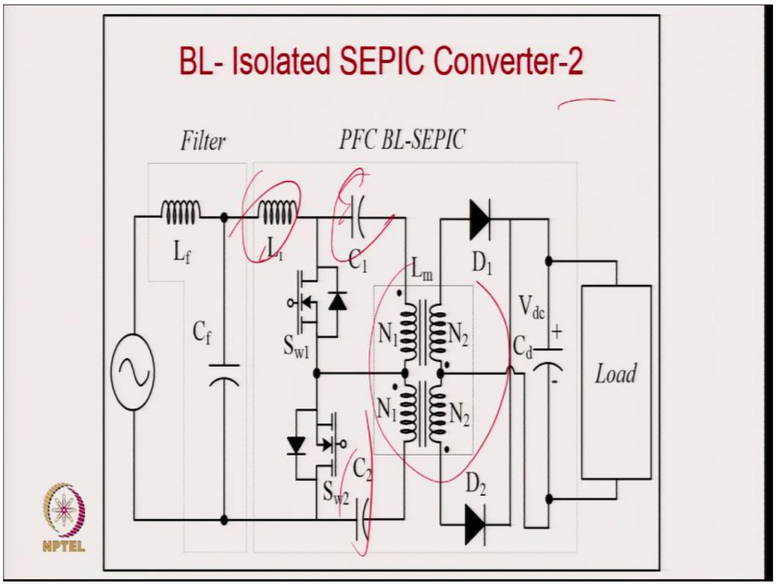

And this is the second bridgeless version of isolated SEPIC IPQC. In this, the diode bridge is completely eliminated.

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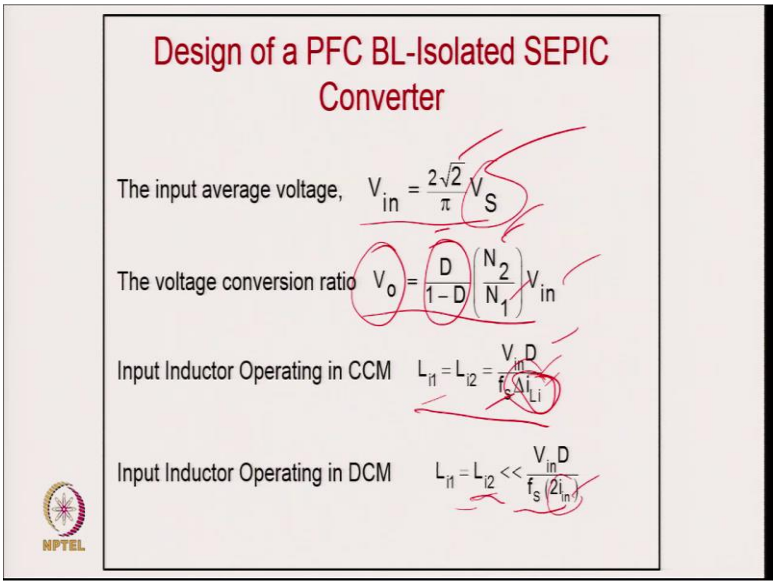

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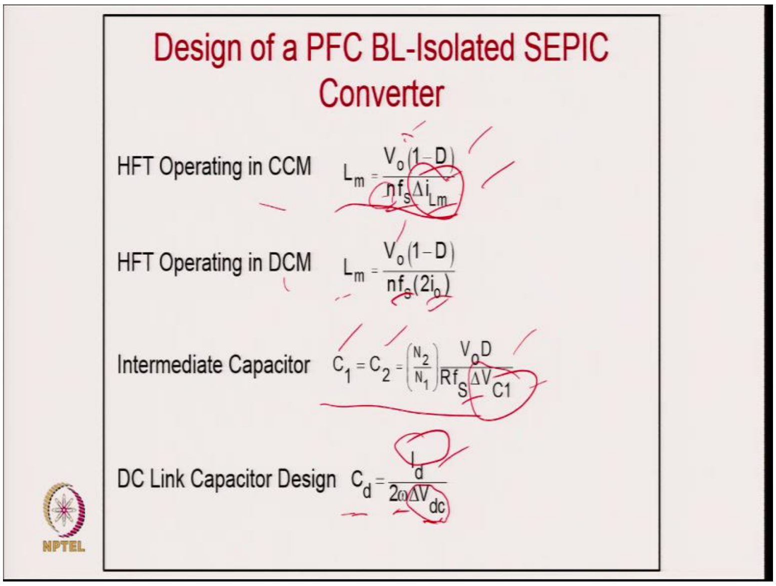

And, these are the design equations for the isolated bridgeless SEPIC IPQCs under both CCM and DCM operation.

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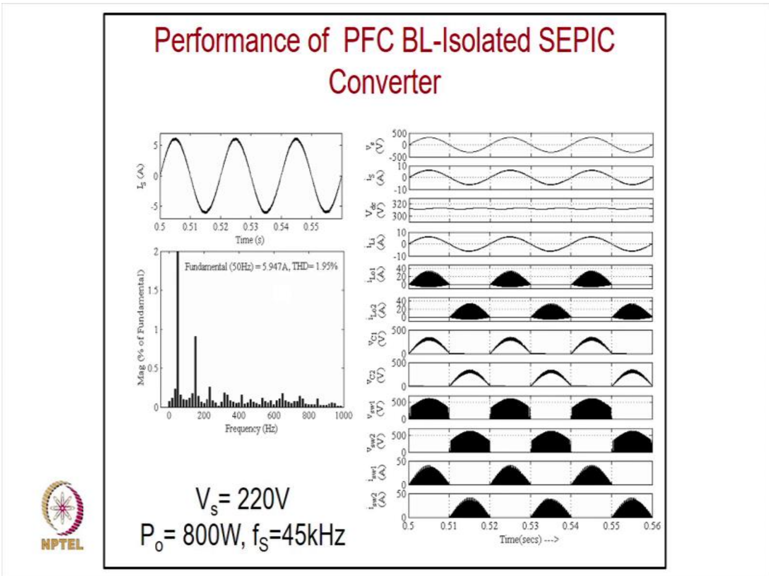

Well, after the design corresponding to 800 W, 220 V, 45 kHz; these are the typical waveforms, which includes supply voltage, supply current and DC link voltage. You can see, both pair of output inductor current remain in discontinuous mode operation. You can see, the THD even less than 2%, i.e., 1.95%.

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Now coming to the analysis, design, simulation and performance of power factor corrected isolated bridgeless zeta converter.

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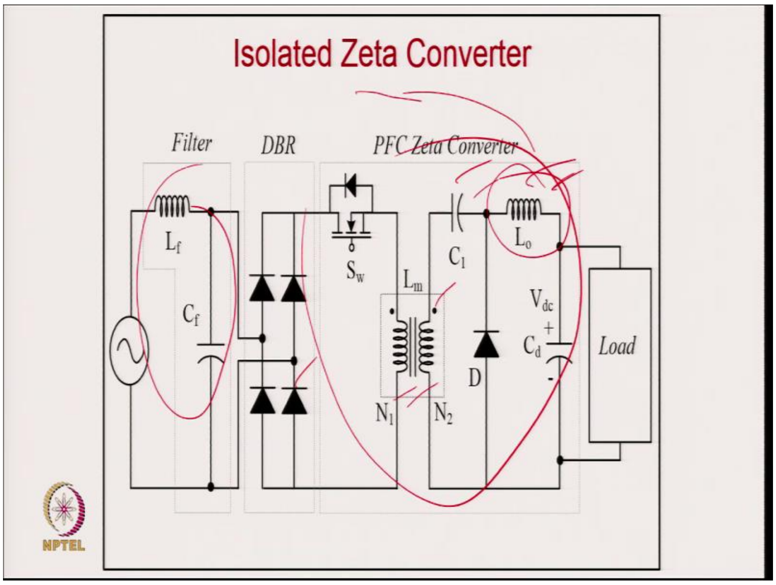

This is the typical isolated zeta IPQC, which have an EMI filter, the diode rectifier and isolated zeta converter. Here, the number of components is same as Cuk, SEPIC converter. Here, also you have a 3 element, output inductor, energy transfer capacitor, and magnetizing inductor, so, you have total 8 design choices.

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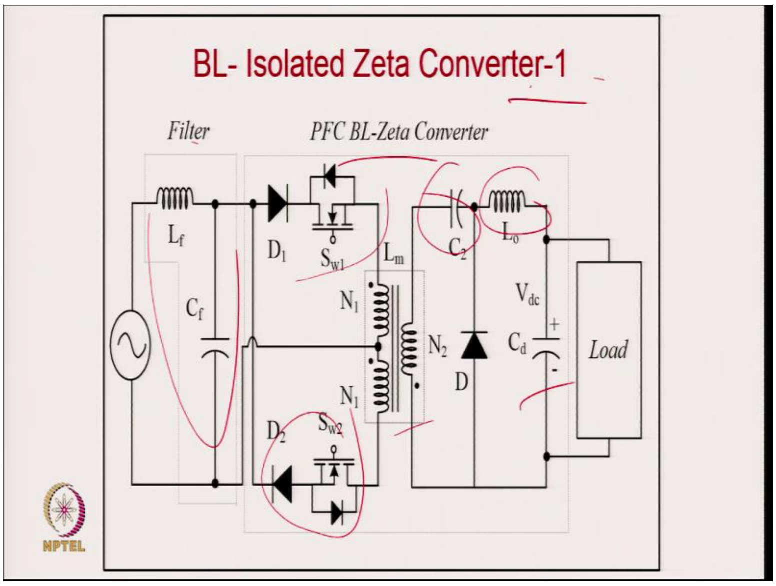

And this is the first bridgeless version of isolated zeta converter with power factor correction.

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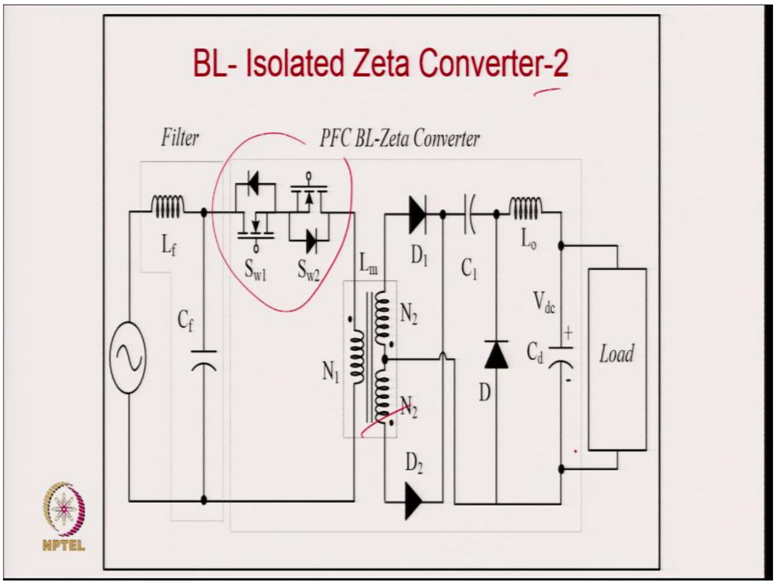

And this is another version of isolated bridgeless zeta IPQC. In this, the 2 switches conduct for positive and negative half cycle, alternatively.

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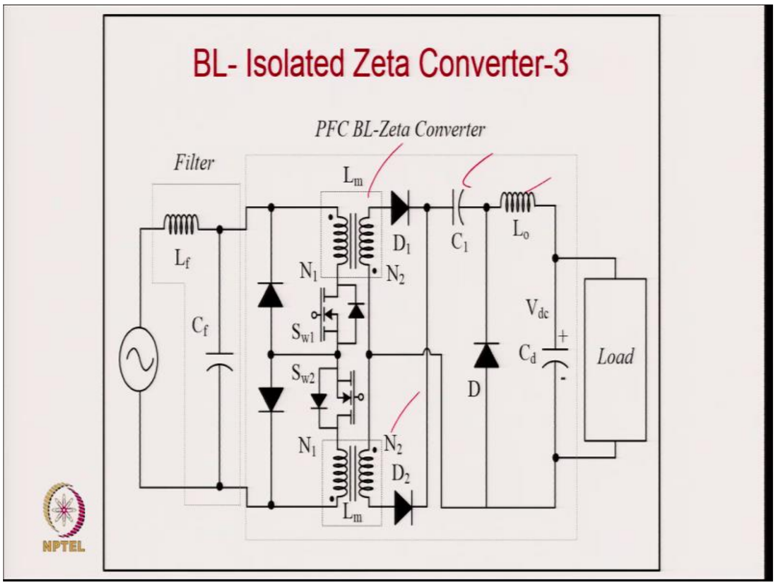

This is the 3rd version of bridgeless isolated Zeta IPQC.

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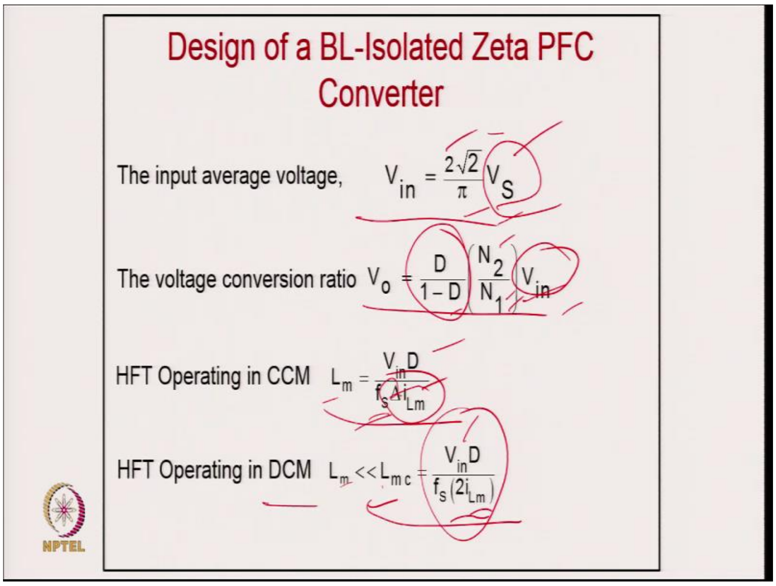

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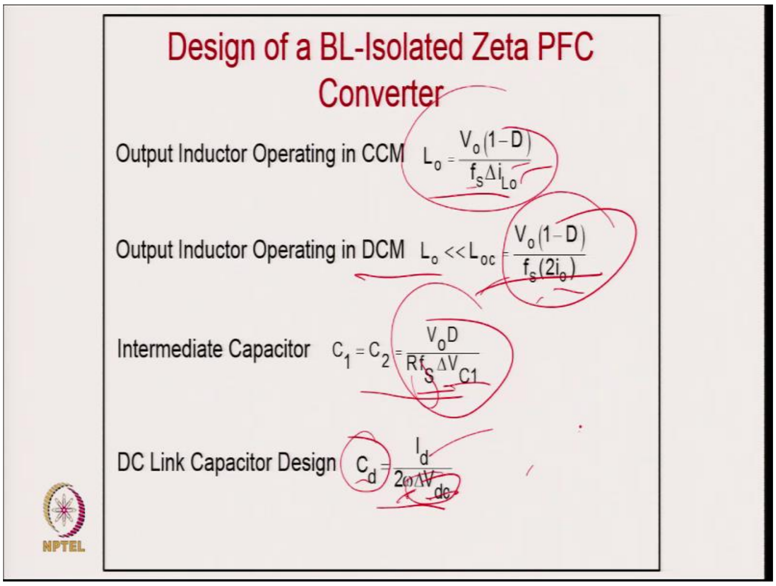

And, these are the design equations for the isolated bridgeless Zeta IPQCs under both CCM and DCM operation.

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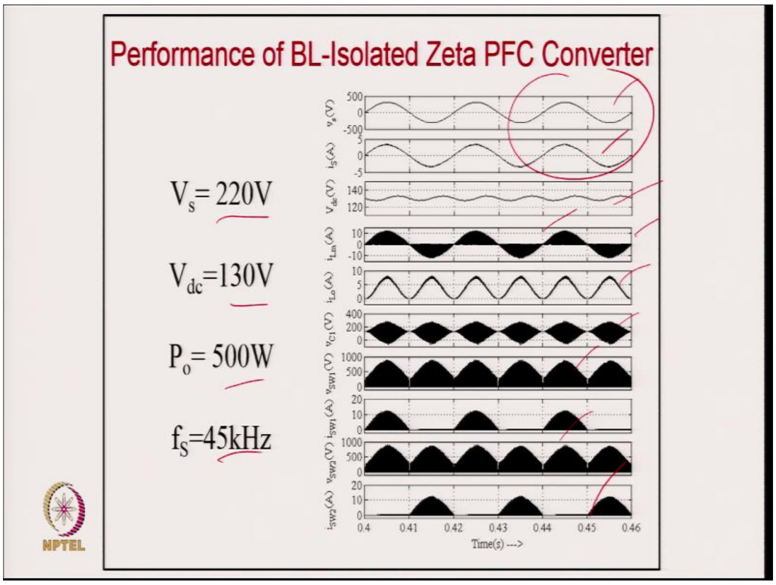

After, designing this converter for input voltage of 220 V, output voltage of 130 V, power of 500 W, and at 45 kHz, this is the simulated performance of isolated bridgeless zeta IPQC.

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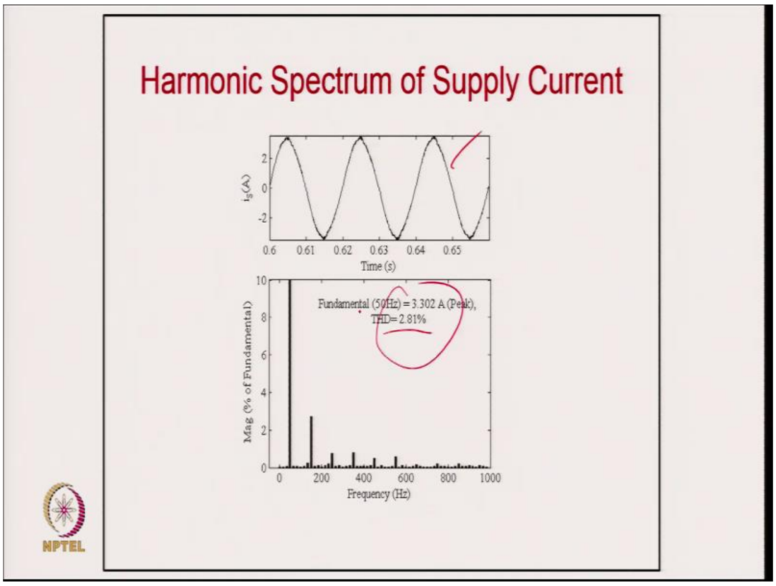

This is the THD of supply current. The THD is found nearly 2.81%.

Thank you.