Power Quality
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Chapter - 14
Lecture - 39
Multipulse Converters (Contd.)

Welcome to the course on Power Quality. We will carry forward the discussion of multipulse converter.

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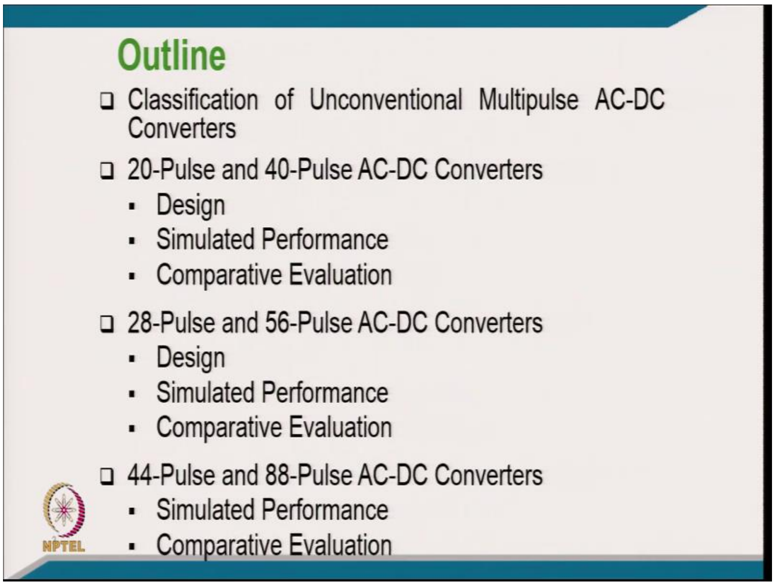

Today, we will talk about the classification of unconventional multipulse AC-DC converter.

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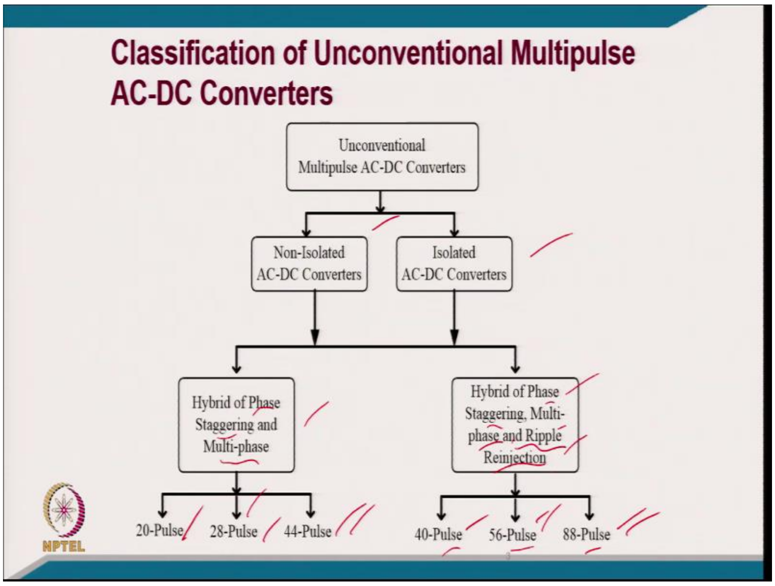

This is the classification of unconventional multipulse AC-DC converters.

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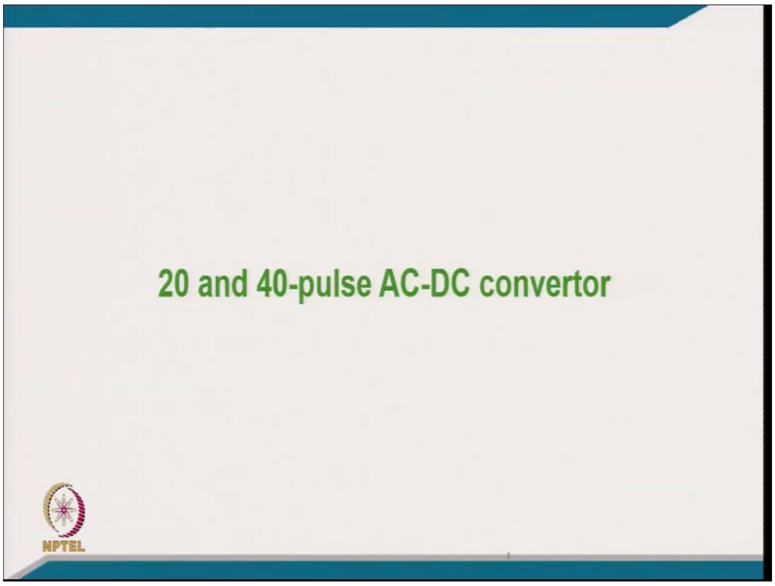

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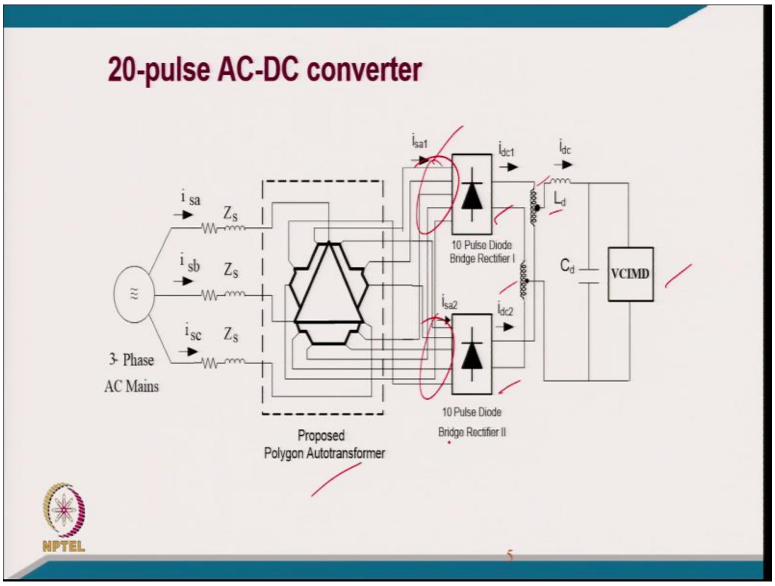

So, coming to 20 and 40-pulse converters. Here, you can see this, first we are taking non-isolated. In this, we are taking out of transformer and 3-phase supply with the help of this polygon autotransformer is converted into two 5-phase supply. So, two sets of 5-phases are phase staggered from each other, then you have two 10-pulse converters and of course, we combine them together. Load may be like simply a vector controlled induction drive or any other load for which you require input power quality improvement. But, there may be another load also which require a kind of DC voltage source with the unidirectional power flow.

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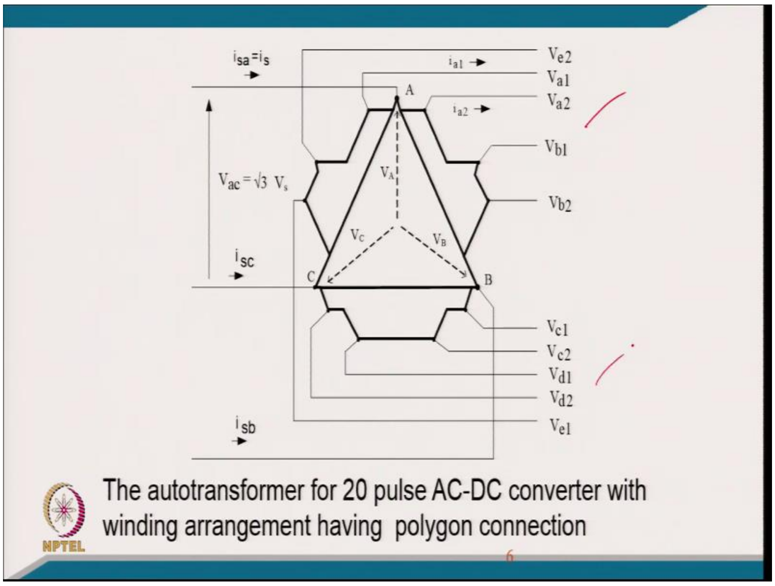

And, this is typically the connection of the transformer.

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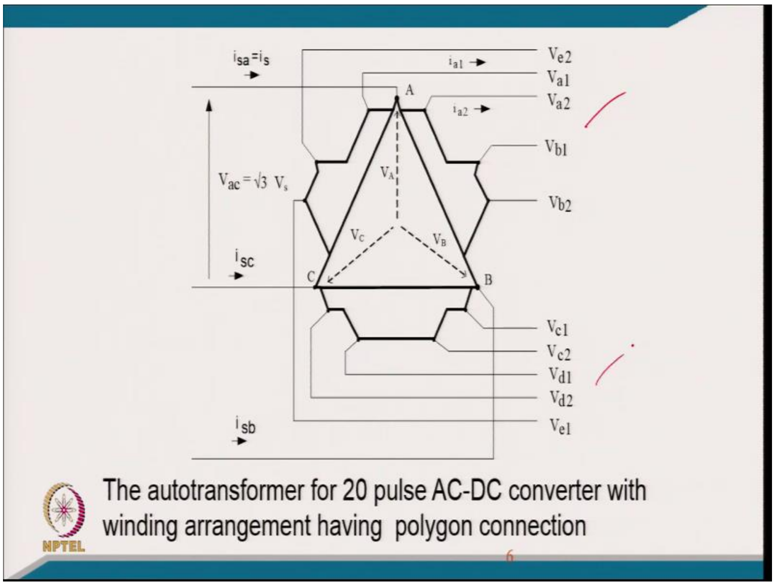

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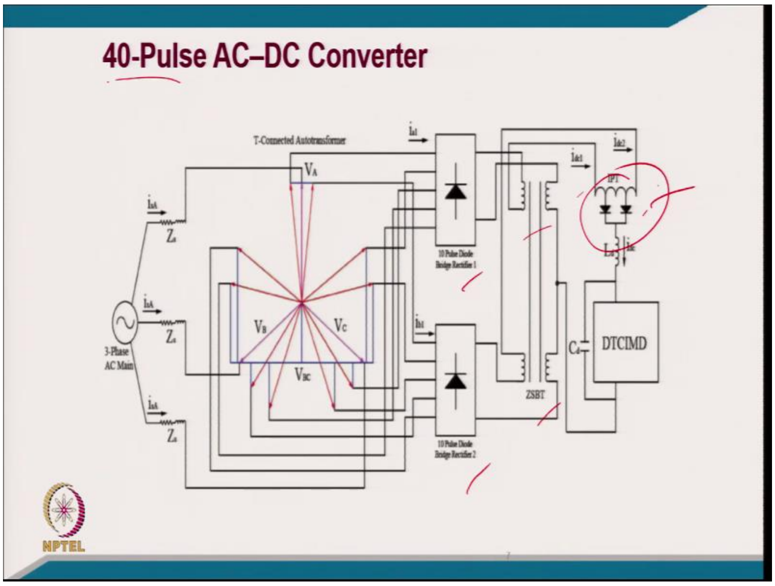

And, this is another transform connection which you can call it a T connection transformer.

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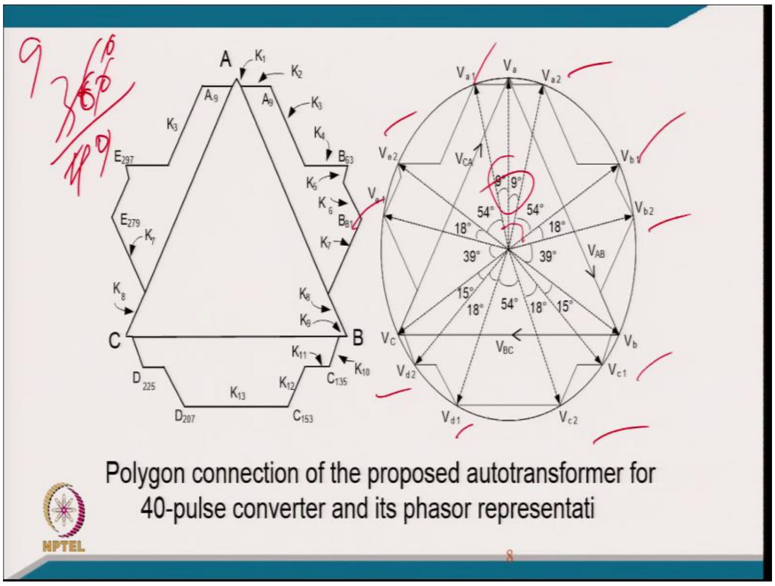

And, this is the typically the phasor diagram which has typical phase staggering.

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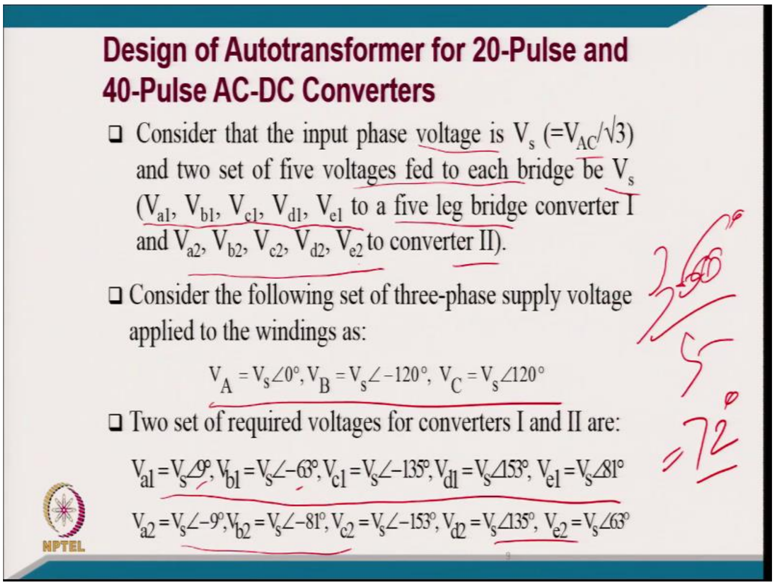

And, these are the design considerations of autotransformer for 20 pulse and 40 pulse AC-DC converters.

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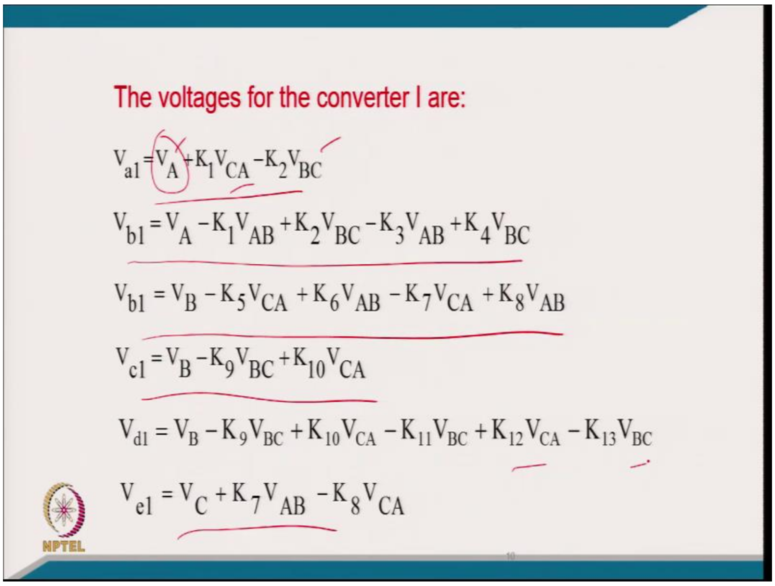

These are the voltages for the converter-I

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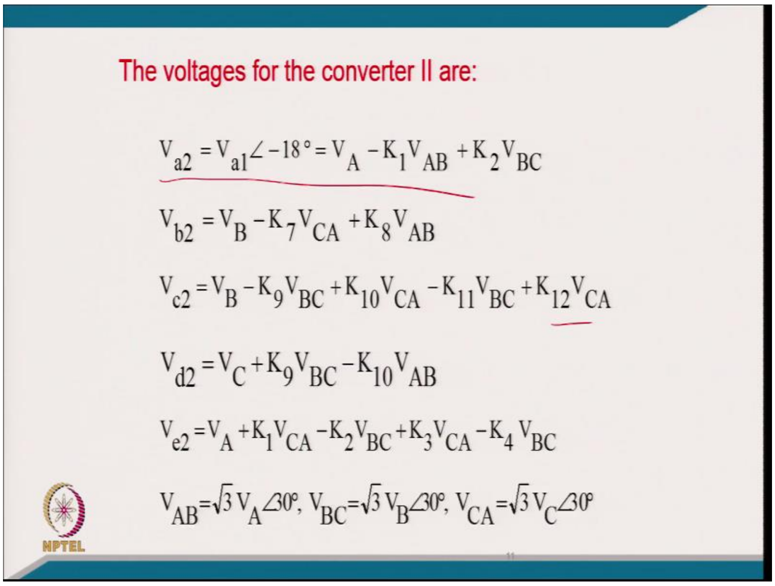

And, these are the voltages for the converter-II.

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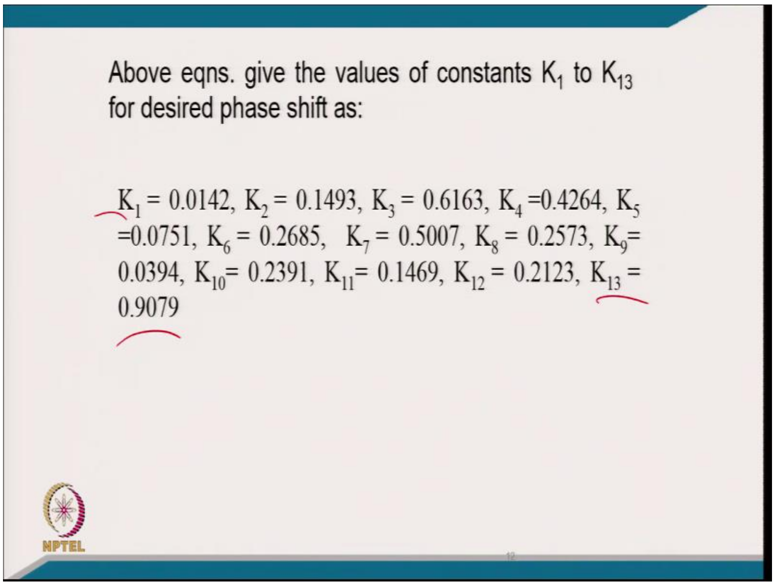

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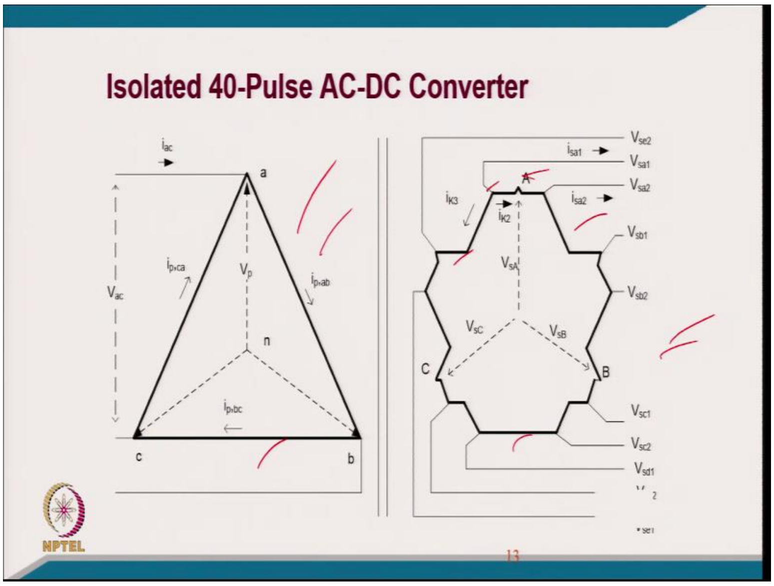

And, this is isolated 40 pulse AC-DC converter. So, primary is normal delta connected and the secondary is connected in delta polygon connection for getting a proper-phase shift.

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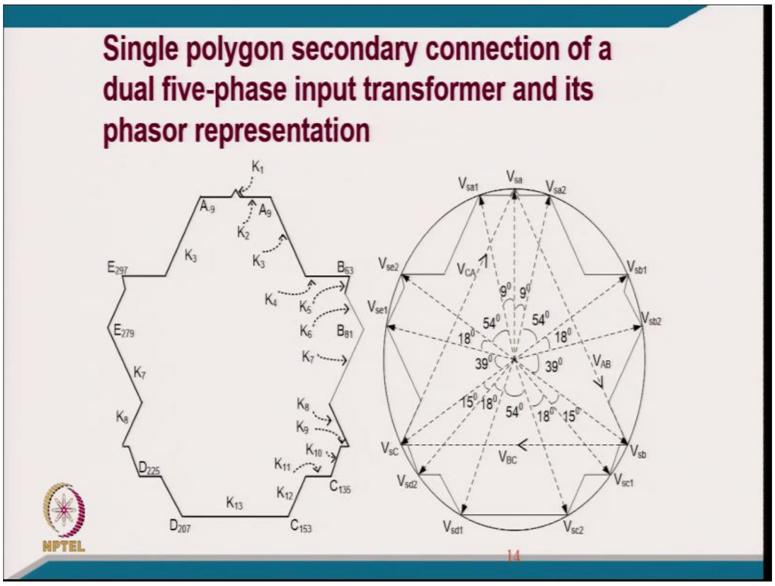

And, this is the typically phasor diagram.

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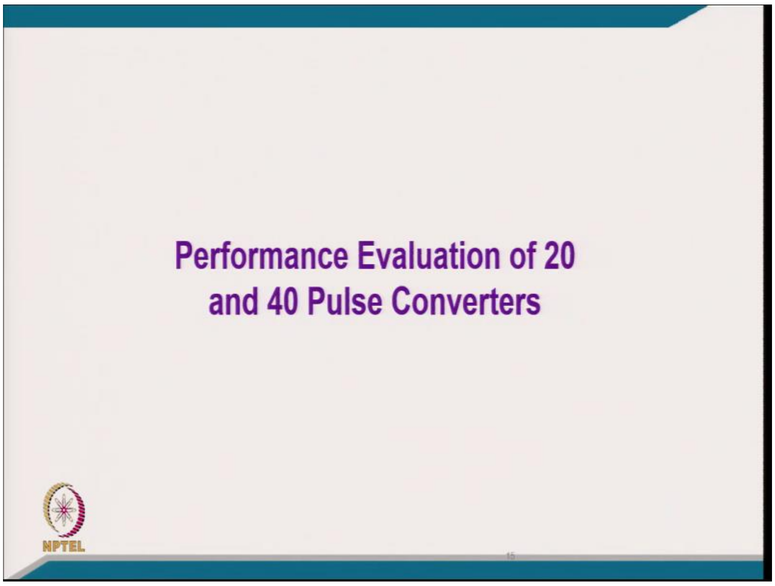

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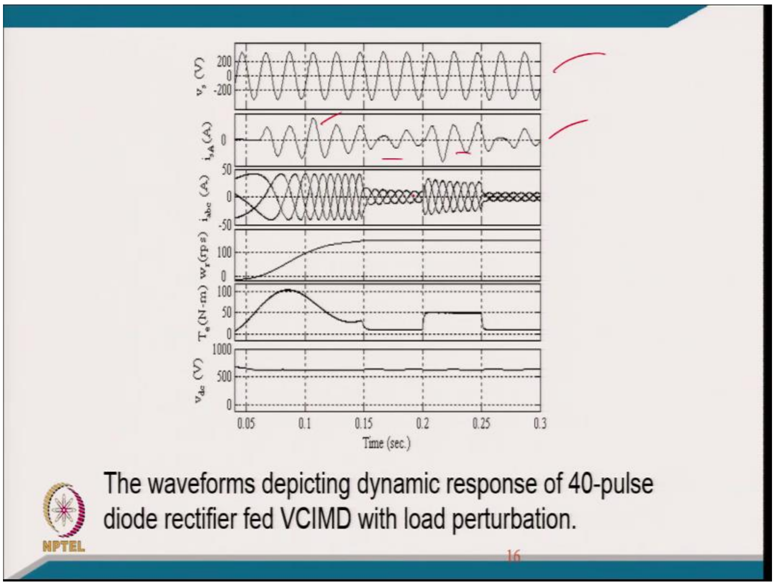

And, now coming to the performance of 40 pulse diode rectifier fed VCIM drive. This is supply voltage, this is current and when during starting of course, it takes more current from supply but once it comes to steady state almost at no load or little higher load it draws more current, but you can see the supply current remain sinusoidal as well as balance.

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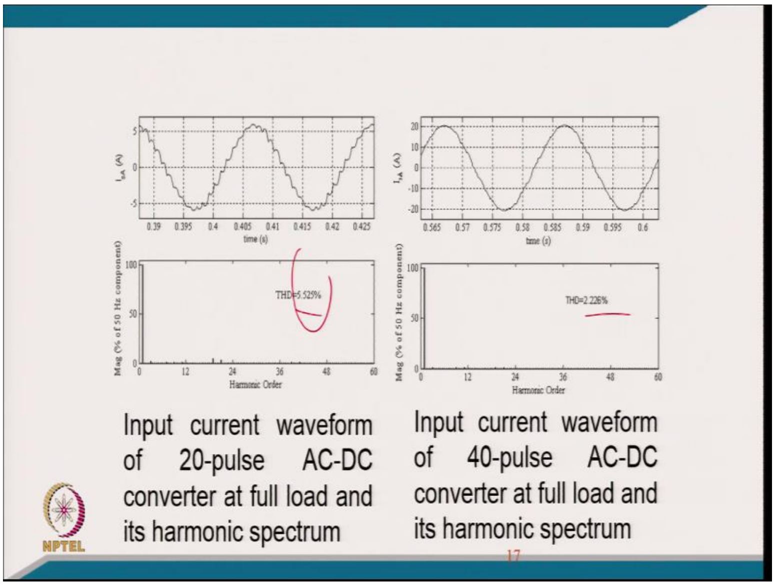

And, this is the THD you are getting typically of 5.5 percent of the current at light load condition and at full load condition you are getting the THD of 2.23 percent. Of course, we are not considering the leakage reactance of the transformer substantially here, but you can adjust the leakage reactance. And the THD can also reduce much lesser than 5 percent and we are considering the typically filter only the capacitive filter.

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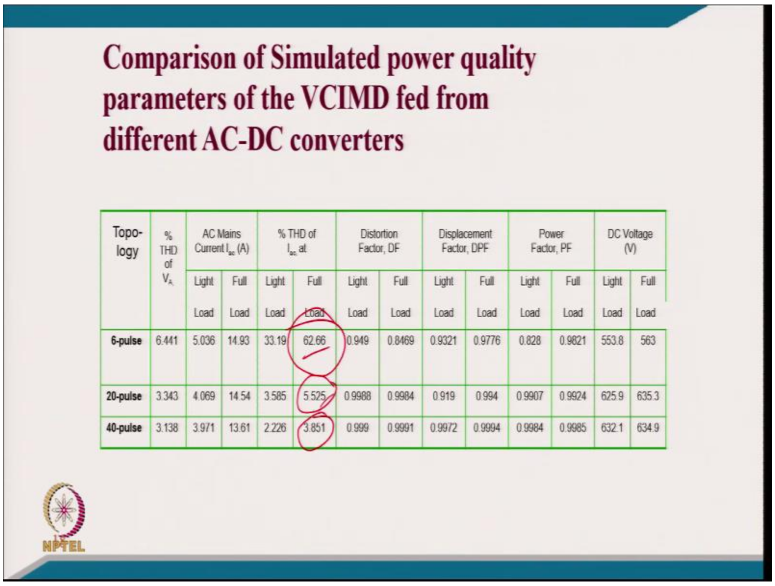

Topology	% THD of V_A	AC Mains Current I_{ac} (A)		% THD of I_{ac} at		Distortion Factor, DF		Displacement Factor, DPF		Power Factor, PF		DC Voltage (V)	
		Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load
6-pulse	6.441	5.036	14.93	33.19	62.66	0.949	0.8469	0.9321	0.9776	0.828	0.9821	553.8	563
20-pulse	3.343	4.069	14.54	3.585	5.525	0.9988	0.9984	0.919	0.994	0.9907	0.9924	625.9	635.3
40-pulse	3.138	3.971	13.61	2.226	3.851	0.999	0.9991	0.9972	0.9994	0.9984	0.9985	632.1	634.9

And, this is a comparative analysis of simulated power quality parameters of VCIMD fed from different AC-DC converters.

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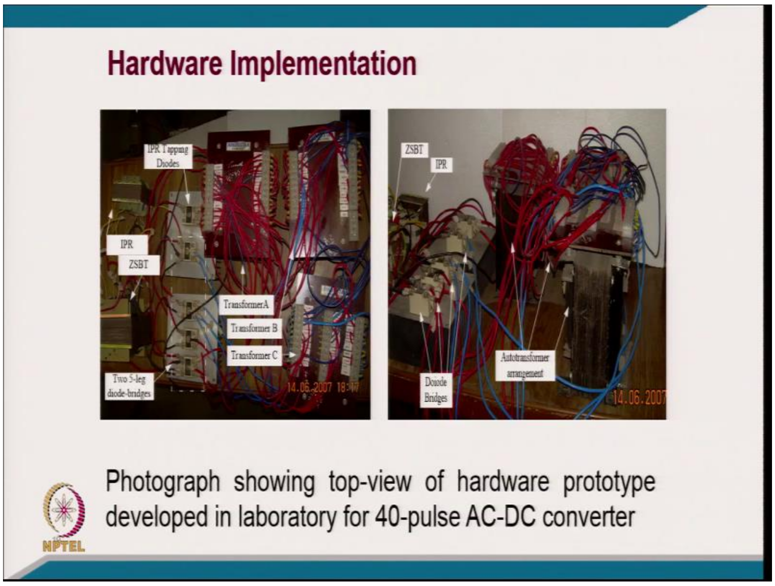

And, this is photograph of prototype which has been designed and developed in the laboratory environment.

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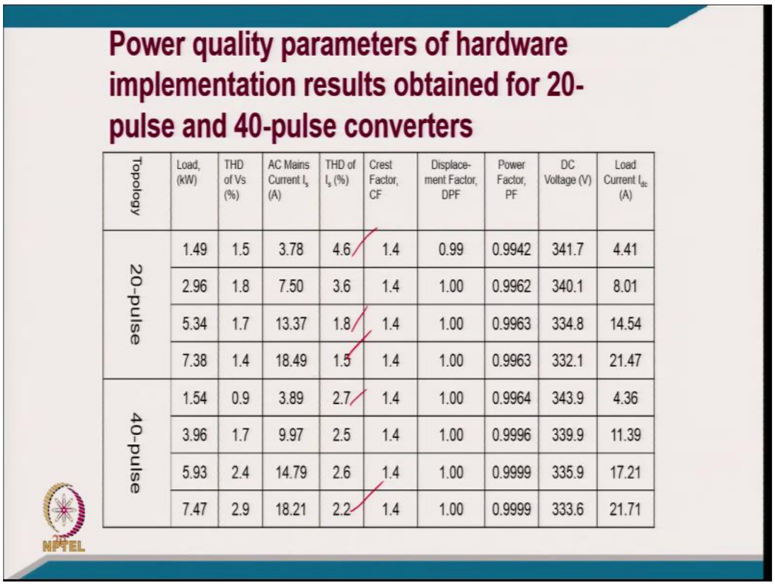
Power quality parameters of hardware implementation results obtained for 20-pulse and 40-pulse converters

Topology	Load, (kW)	THD of Vs (%)	AC Mains Current I_s (A)	THD of I_s (%)	Crest Factor, CF	Displacement Factor, DPF	Power Factor, PF	DC Voltage (V)	Load Current I_{dc} (A)
20-pulse	1.49	1.5	3.78	4.6	1.4	0.99	0.9942	341.7	4.41
	2.96	1.8	7.50	3.6	1.4	1.00	0.9962	340.1	8.01
	5.34	1.7	13.37	1.8	1.4	1.00	0.9963	334.8	14.54
	7.38	1.4	18.49	1.5	1.4	1.00	0.9963	332.1	21.47
40-pulse	1.54	0.9	3.89	2.7	1.4	1.00	0.9964	343.9	4.36
	3.96	1.7	9.97	2.5	1.4	1.00	0.9996	339.9	11.39
	5.93	2.4	14.79	2.6	1.4	1.00	0.9999	335.9	17.21
	7.47	2.9	18.21	2.2	1.4	1.00	0.9999	333.6	21.71

And, these are the power quality parameters of hardware implementation results obtained for 20 and 40 pulse converters.

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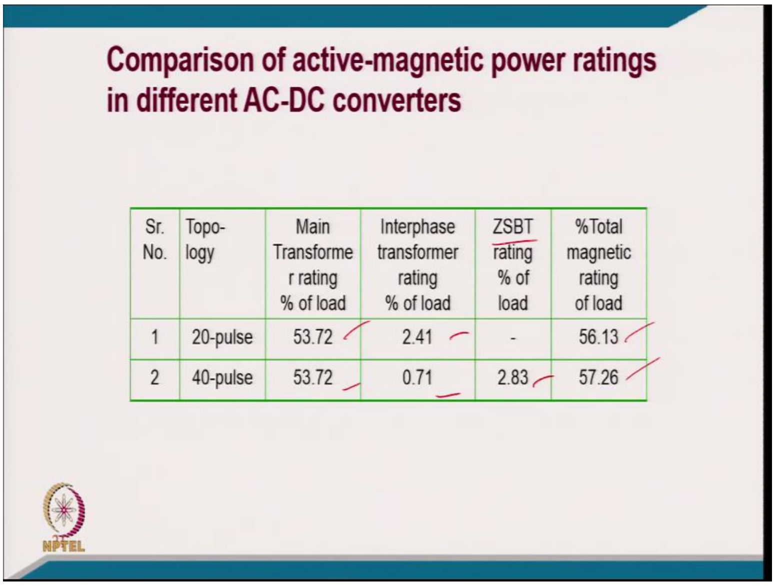
Comparison of active-magnetic power ratings in different AC-DC converters

Sr. No.	Topology	Main Transformer rating % of load	Interphase transformer rating % of load	ZSBT rating % of load	%Total magnetic rating of load
1	20-pulse	53.72	2.41	-	56.13
2	40-pulse	53.72	0.71	2.83	57.26

And, this is the comparison of active magnetic power ratings in different AC-DC converters.

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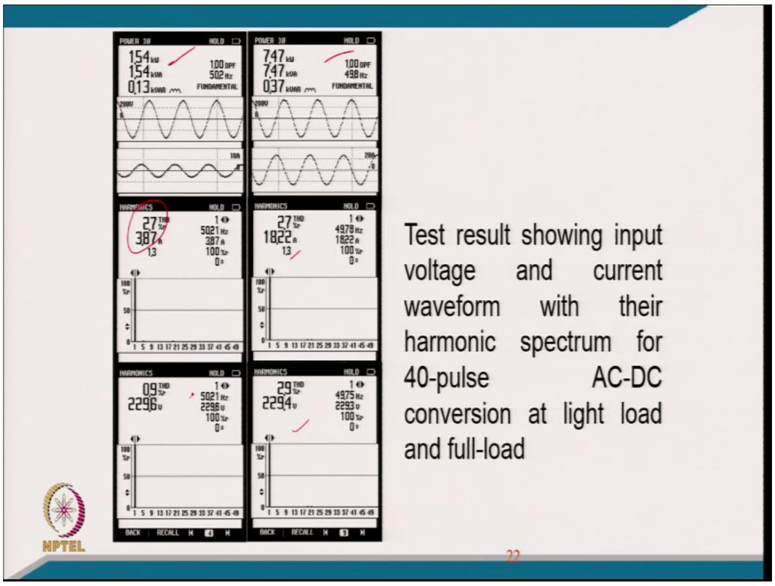

And, these are the test results showing input voltage and current waveform with their harmonics spectrum for 40-pulse AC-DC conversion at light load and full load.

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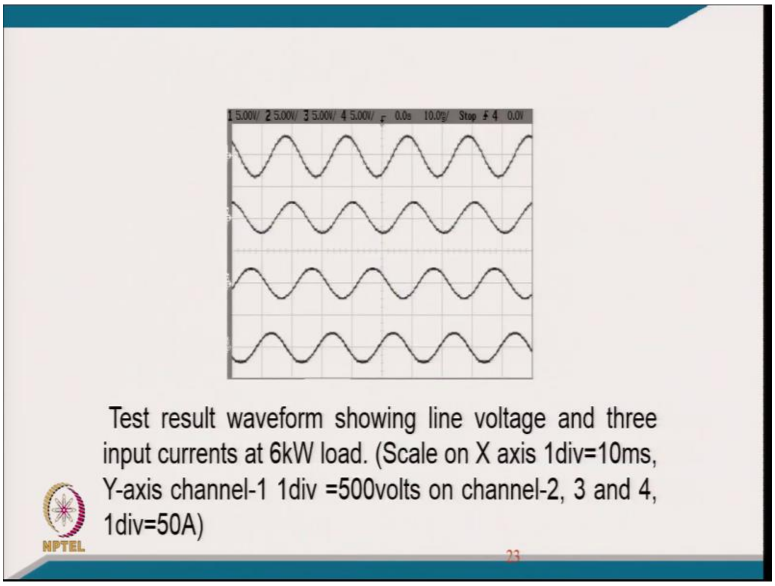

And, this is the 3-phase supply current along with the voltage how it looks like almost like a sinusoidal current.

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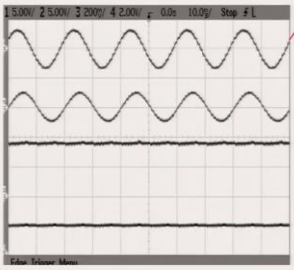

Test result waveform showing input voltage and current waveform along with DC voltage and current waveform. (Scale on X axis 1 div =10ms, Y-axis channel-1, 1 div =500volts; channel-2, 1 div =50A: channel 3, 1 div =200V; channel 4, 1div=20A)

And, this is the of course, the supply voltage, supply current, load voltage, and load current.

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Isolated 40-Pulse AC-DC converter

Topology	%THD V_{ac}	% THD of I_{ac}, at		DF	DPF			PF		DC Voltage (V)	
		Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load
6-pulse	4.056	24.81	27.93	.9815	.9943	.9698	.963	.9519	.9575	279.2	294.4
12-pulse	3.278	9.730	12.19	.9915	.9987	.9947	.992	.9863	.9912	283.7	288.7
18-pulse	1.487	2.776	5.360	.9776	.9897	.9995	.998	.9771	.9883	289.1	297.3
20-pulse	3.091	4.874	6.917	.9952	.9980	.9984	.997	.9936	.9955	300.0	302.9
40-pulse	1.350	2.060	2.533	.9919	.9979	.9997	.999	.9916	.9975	291.7	303.1

And, these are the comparison result of 40-pulse AC-DC converter with 6,12,18, and 20 pulse AC-DC converters.

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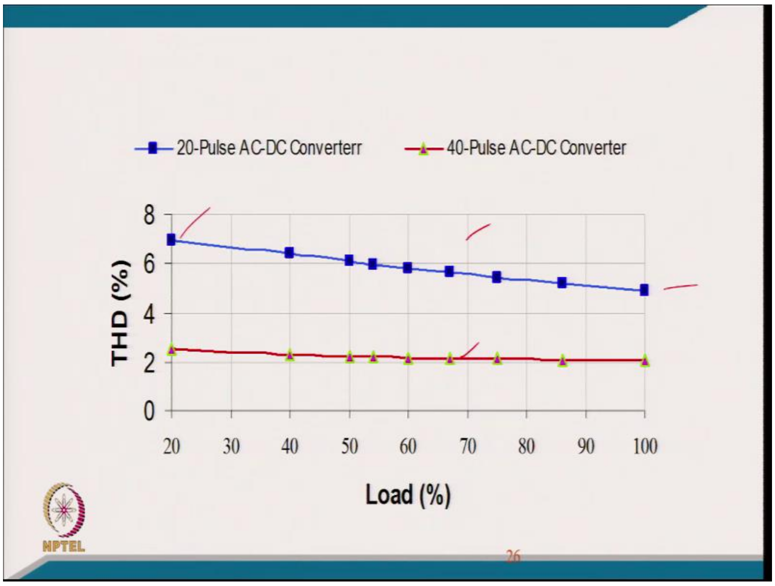

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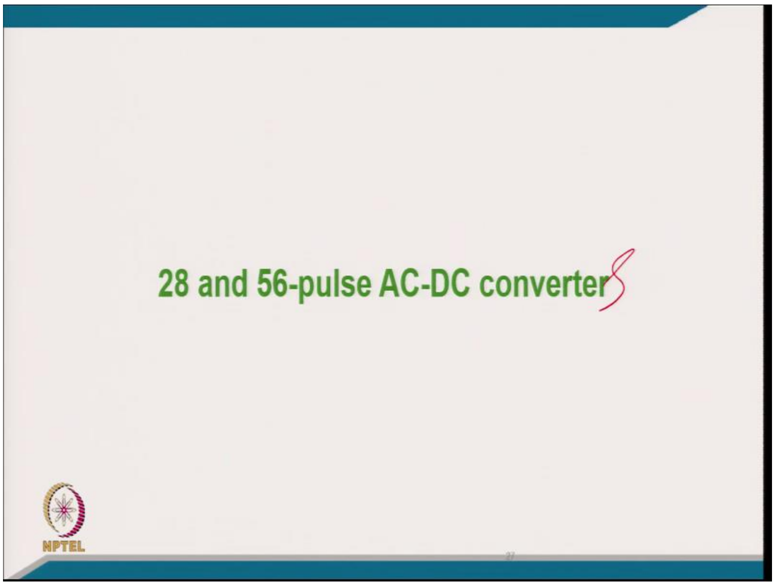

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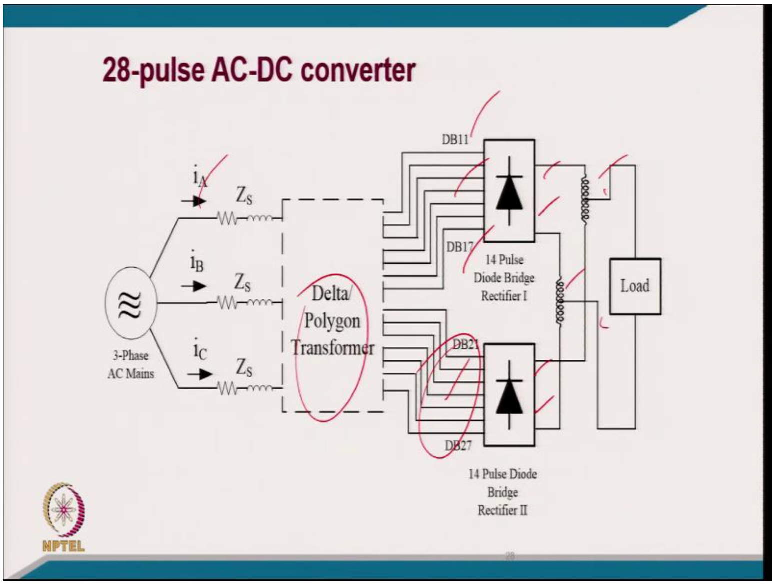

Now, coming to another set of unconventional converter of 28-pulse and 56-pulse converters. Here, we are converting virtually the 3-phase supply with the help of this delta polygon transformer to two sets of 7 phases. I mean like, this is one 7-phases set and this is another set of 7 phases and that we are rectifying, this is giving two sets of 14-pulses and this interface transformer convert it into typically 28-pulse converter.

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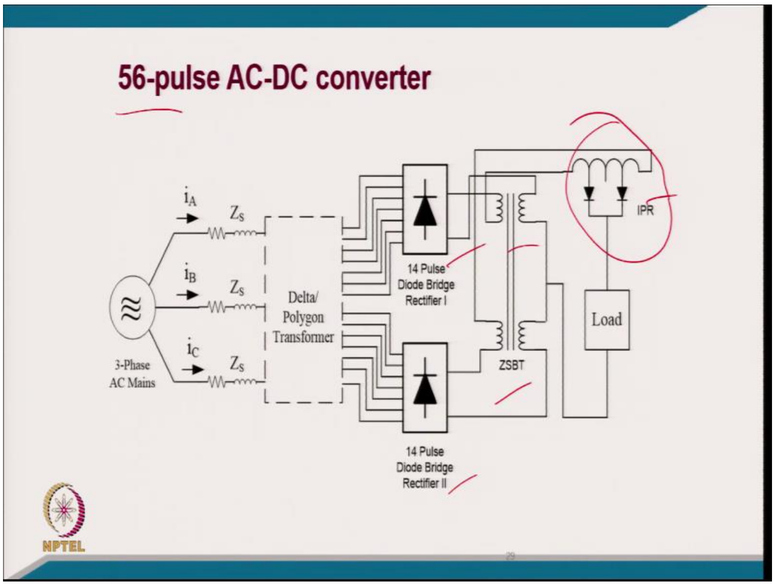

And, if you want to go for 56-pulse pulse by doubling or by ripple injection, then you have to use ZSBT here. So, with the help of ripple injection circuit i.e., by the interface transformer and 2 diodes, we are able to get 56-pulse converter.

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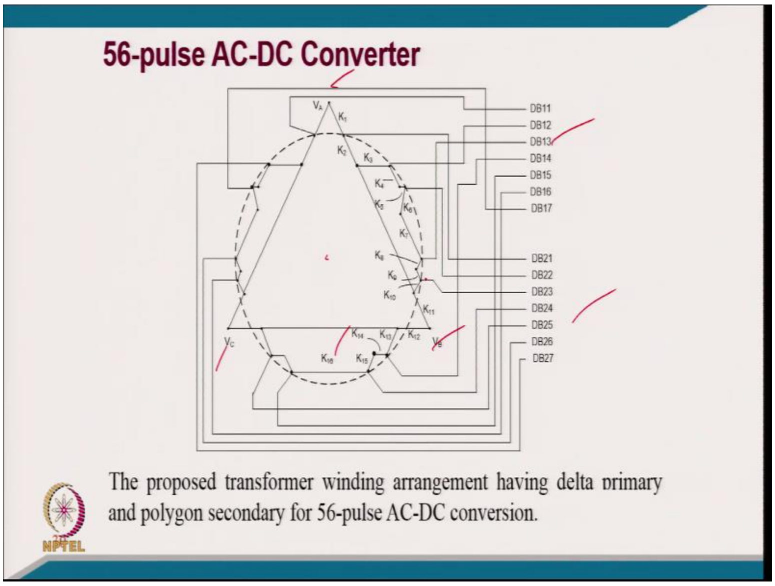

And, these are the typical transformer connections.

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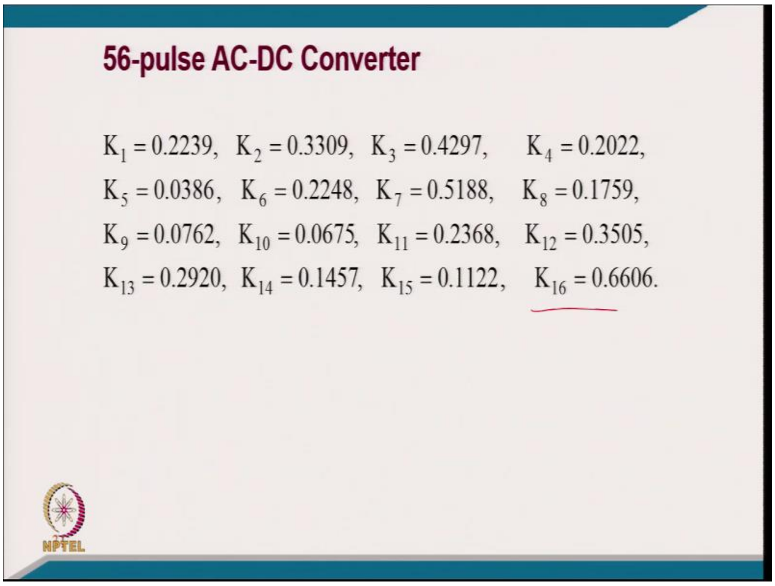

In case of 40-pulse you were getting 13, but, here you are getting 16 constants because you have a several segment of a winding connections.

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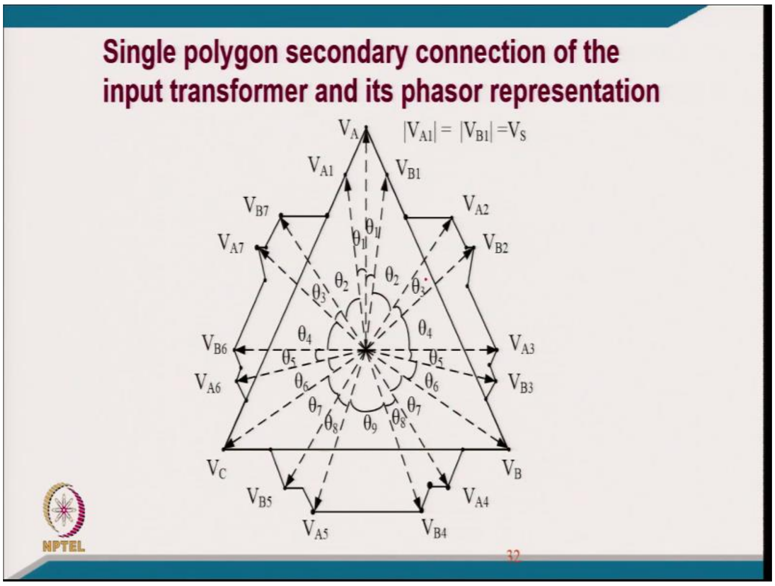

And, this is the typical phasor diagram of single polygon secondary connection of the input transformer.

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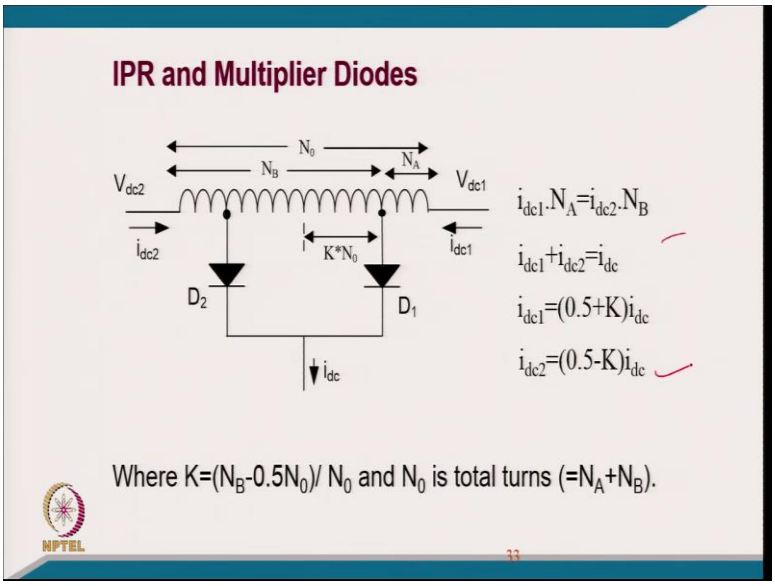

And, this is the interface transformer, I mean, with the pulse doubling or ripple injection you can make the-pulse double by using these relations.

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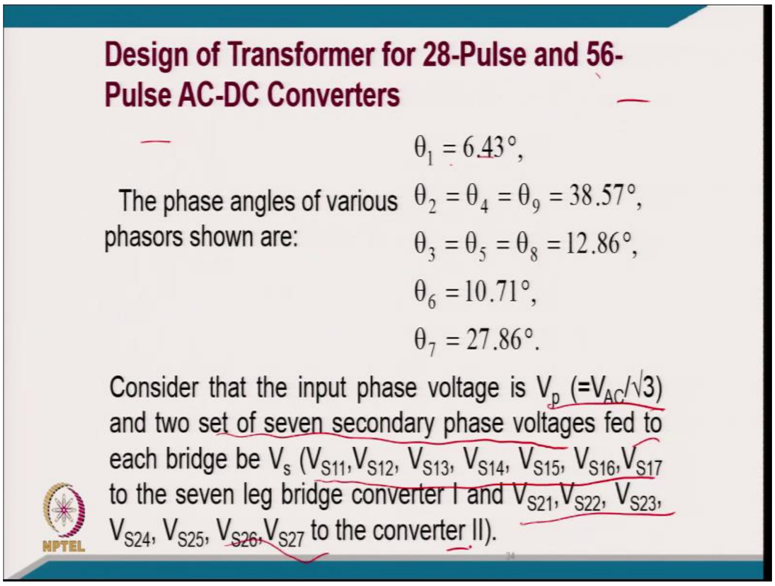

And, these are the different angles, which you are finding for the design of this 28-pulse AC-DC converter and 56-pulse AC-DC converter.

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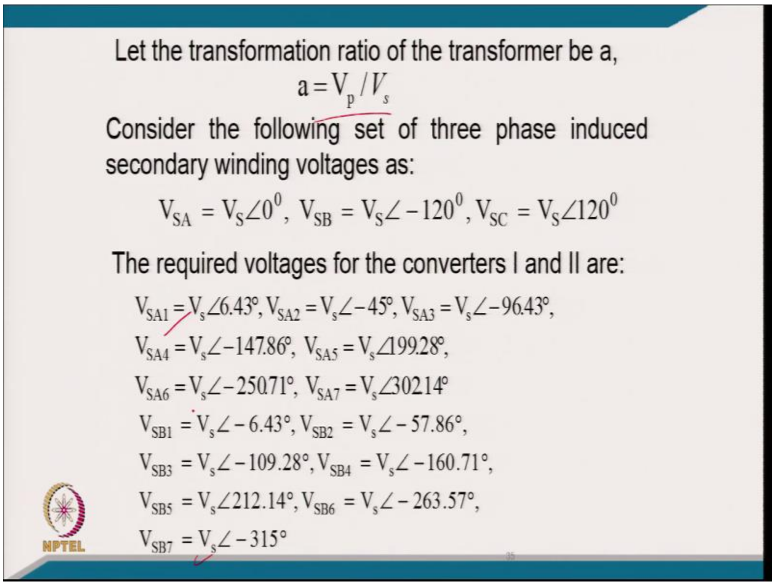

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The voltages for the converter I are:

$$V_{SA} = V_{SA1} - K_1 V_{SCA} = V_{SB1} - K_1 V_{SAB}$$

$$V_{SA2} = V_{SA} - (K_1 + K_2) V_{SAB} + K_3 V_{SBC}$$

$$V_{SA3} = V_{SA2} + K_5 V_{sCA} - K_6 V_{sAB} - K_7 V_{sBC} - K_8 V_{sAB}$$

$$V_{SA4} = V_{SB} - K_{12} V_{sBC} + K_{13} V_{sCA}$$

$$V_{SA5} = V_{SC} + (K_{12} + K_{14}) V_{sBC} - (K_{13} + K_{15}) V_{SAB}$$

$$V_{SA6} = V_{SC} + K_{11} V_{SCA} + K_{10} V_{SAB}$$

$$V_{SA7} = V_{SA1} + (K_2 + K_4) V_{SCA} - (K_3 + K_5) V_{SBC}$$

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The voltages for the converter II are:

$$V_{SB1} = V_{SA} + K_1 V_{AB}$$

$$V_{SB2} = V_{SA2} + K_4 V_{SAB} - K_5 V_{SBC}$$

$$V_{SB3} = V_{SB} + K_{11} V_{SAB} - K_{10} V_{SCA}$$

$$V_{SB4} = V_{SA4} - K_{14} V_{SBC} + K_{15} V_{SCA}$$

$$V_{SB5} = V_{SC} + K_{12} V_{SBC} - K_{13} V_{SAB}$$

$$V_{SB6} = V_{SA6} + K_9 V_{SCA} - K_{13} V_{SAB}$$

$$V_{SB7} = V_{SA1} + K_2 V_{SCA} - K_3 V_{SBC}$$

$$V_{sAB} = \sqrt{3} V_{sA} \angle 30^0,\ V_{sBC} = \sqrt{3} V_{sB} \angle 30^0,\ V_{sCA} = \sqrt{3} V_{sC} \angle 30^0$$

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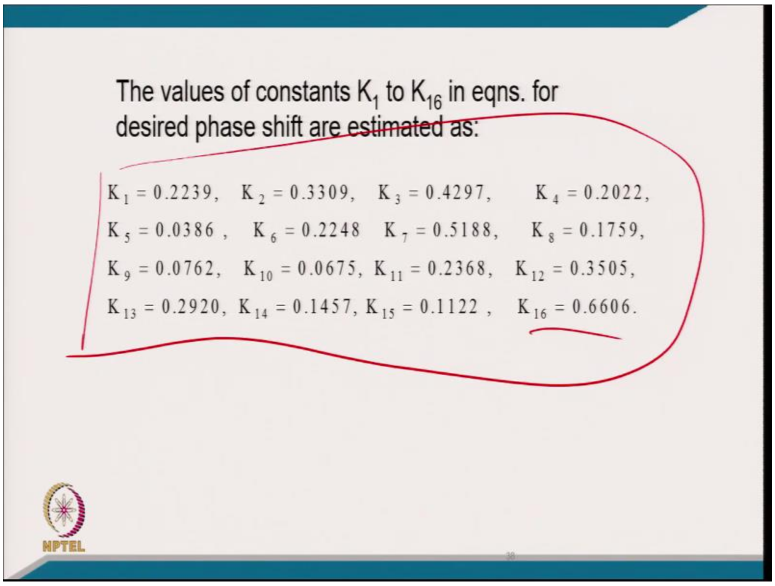

And, these are the all sixteen constant you are getting for this transformer.

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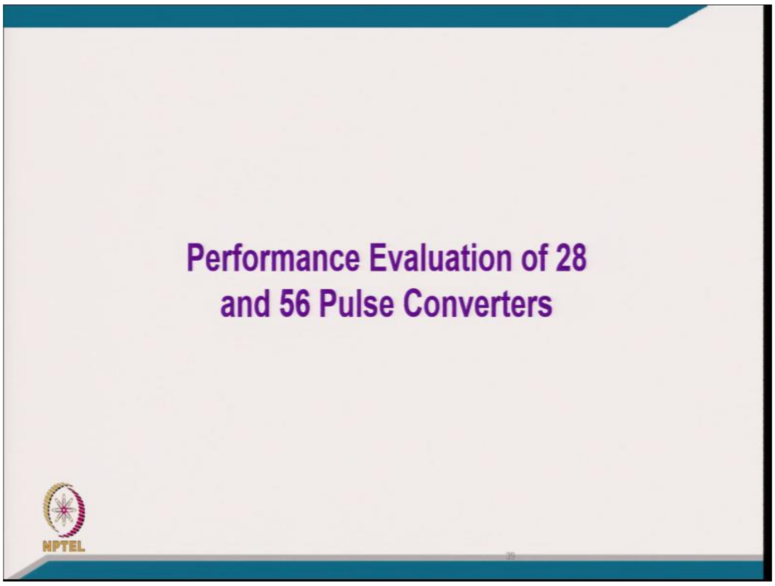

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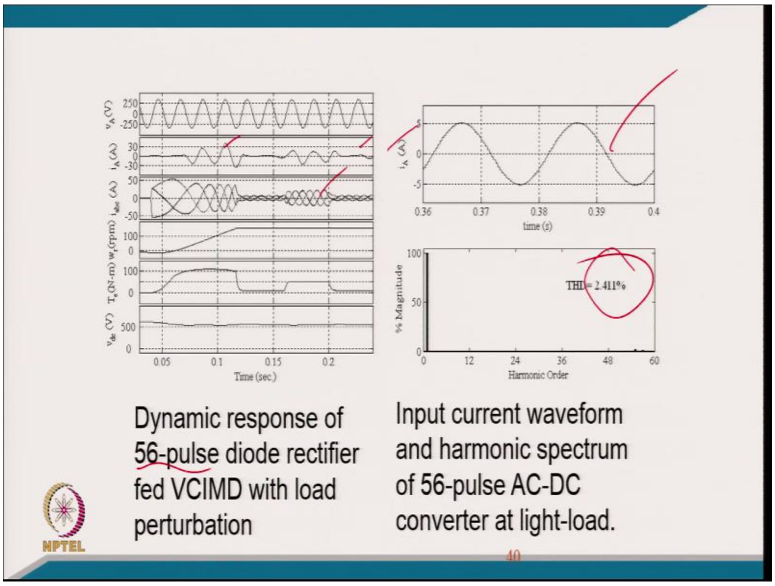

And, now coming to the performance analysis of 28 pulse and 56 pulse AC-DC converters. This is the dynamic response of 56-pulse diode rectifier fed VCIMD with load perturbation.

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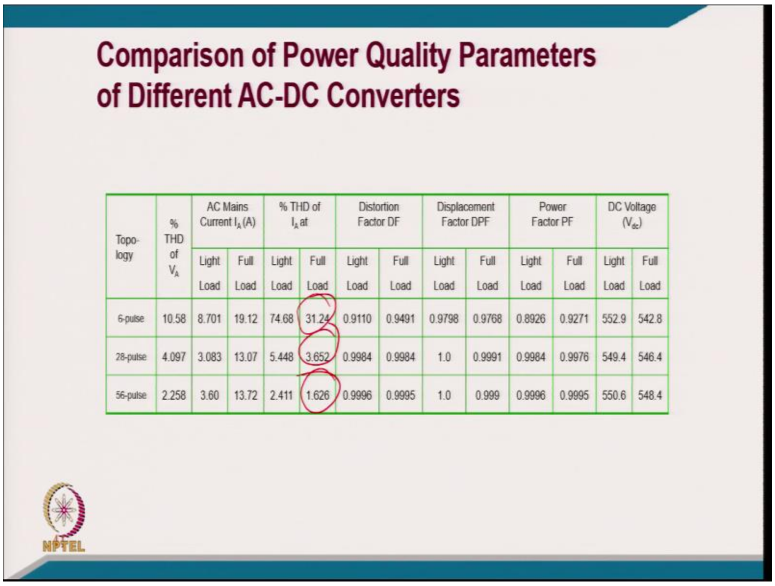

Topology	% THD of V_A	AC Mains Current I_A (A)		% THD of I_A at		Distortion Factor DF		Displacement Factor DPF		Power Factor PF		DC Voltage (V_{dc})	
		Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load
6-pulse	10.58	8.701	19.12	74.68	31.24	0.9110	0.9491	0.9798	0.9768	0.8926	0.9271	552.9	542.8
28-pulse	4.097	3.083	13.07	5.448	3.652	0.9984	0.9984	1.0	0.9991	0.9984	0.9976	549.4	546.4
56-pulse	2.258	3.60	13.72	2.411	1.626	0.9996	0.9995	1.0	0.999	0.9996	0.9995	550.6	548.4

And, this is a comparative analysis of simulated power quality parameters of VCIMD fed from different AC-DC converters.

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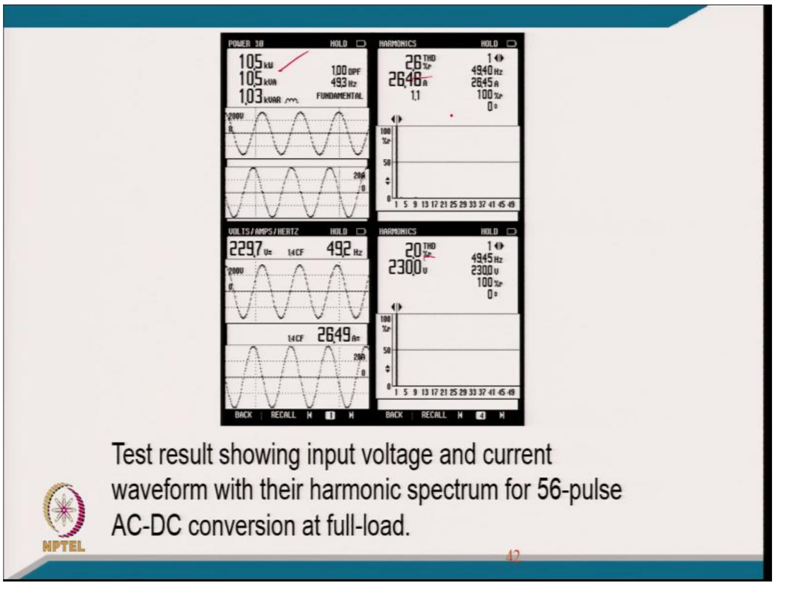

And, these are the test result showing input voltage and current waveform with their harmonic spectrum for 56-pulse AC-DC conversion at full load.

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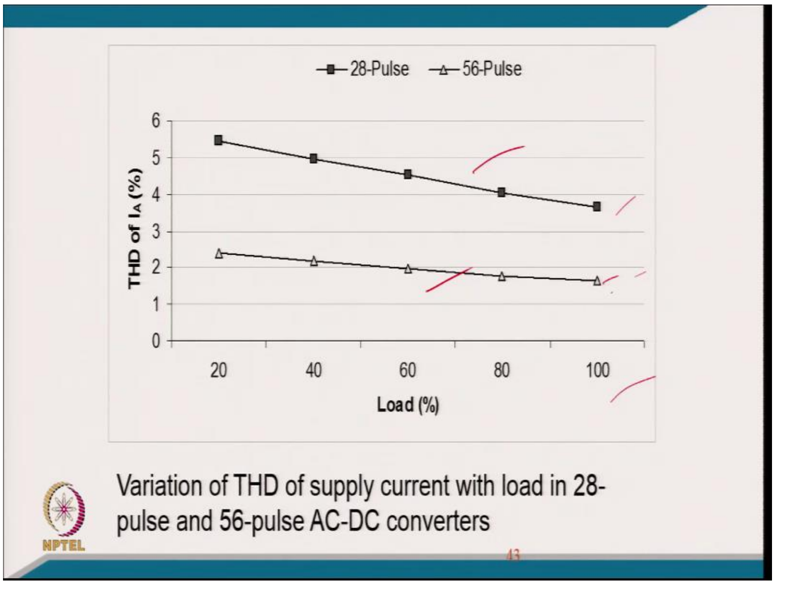

And this is the variation of THD of supply current with load in 28-pulse and 56-pulse AC-DC converter.

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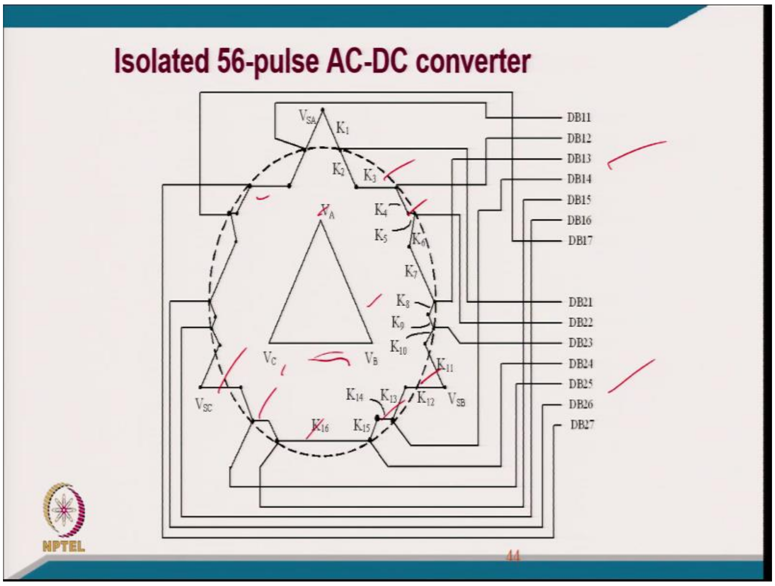

And, this is the isolated 56 pulse AC-DC converter.

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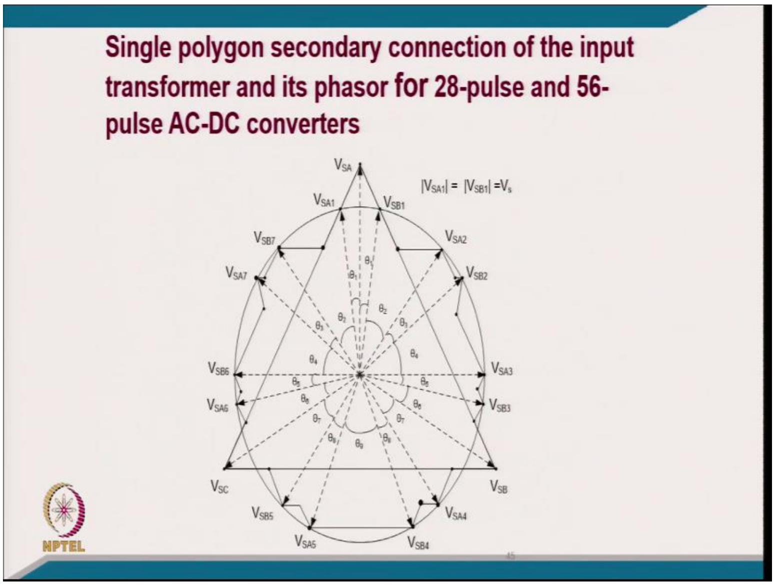
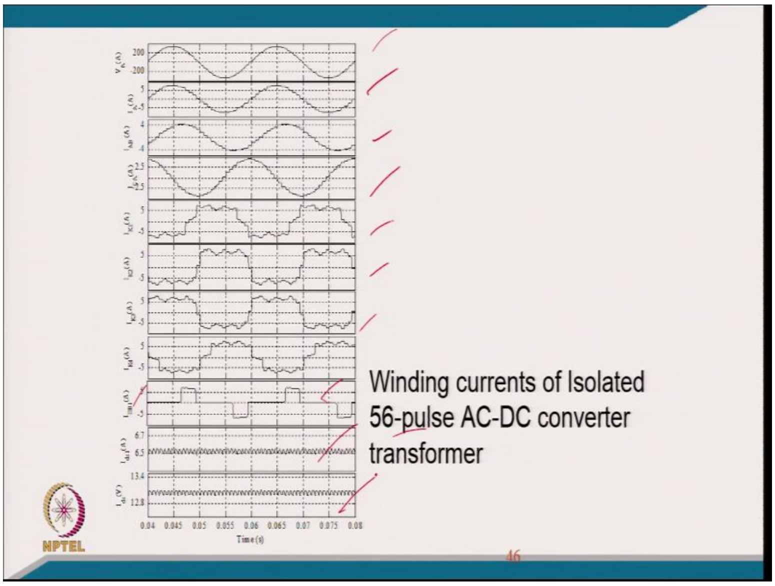


And, this is typically the phasor diagram for 28-pulse and 56-pulse AC-DC converters.

(Refer Slide Time: 24:29)



These are the winding currents of isolated 56-pulse AC-DC converter transformer.

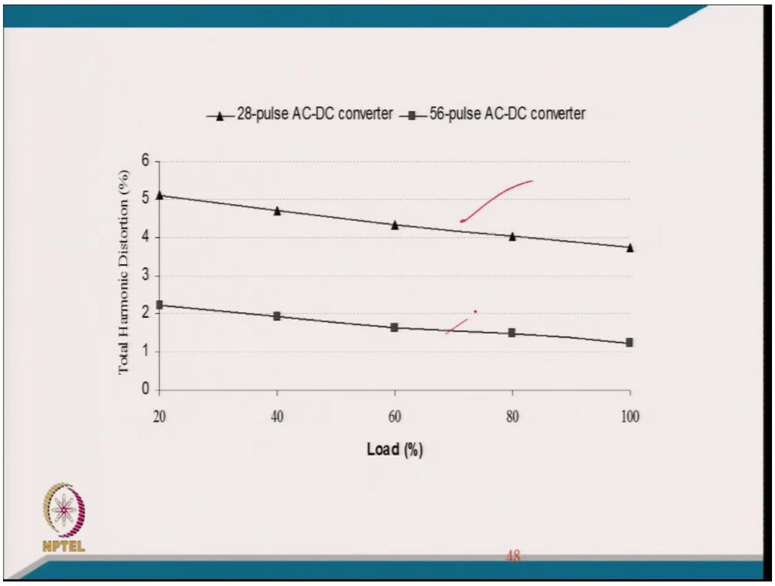
(Refer Slide Time: 24:55)

Comparison Power quality parameters of isolated 28 and 56-pulse AC-DC converters

Topology	Load	THD V_{ac} (%)	AC Mains Current I_{ac} (A)	THD of I_{ac}(%)	DF	DPF	PF	DC Voltage (V)	Load Current I_{dc} (A)	RF (%)
28-pulse	20%	1.218	5.541	5.119	0.9986	1.0000	0.9986	295.9	13.06	0.2202
	40%	1.965	10.92	4.700	0.9987	0.9997	0.9984	295.3	26.04	0.2189
	50%	2.277	13.60	4.512	0.9988	0.9995	0.9983	295.0	32.51	0.2214
	60%	2.561	16.27	4.341	0.9987	0.9994	0.9981	294.8	38.95	0.2239
	80%	3.062	21.59	4.032	0.9987	0.9992	0.9979	294.2	51.79	0.2323
	100%	3.495	26.87	3.759	0.9987	0.9990	0.9977	293.7	64.55	0.2419
56-pulse	20%	0.924	5.558	2.228	0.9997	1.0000	0.9997	296.2	13.08	0.0597
	40%	1.437	10.97	1.932	0.9997	0.9999	0.9996	295.7	26.09	0.0646
	50%	1.630	13.66	1.775	0.9997	0.9999	0.9996	295.4	32.57	0.0658
	60%	1.797	16.35	1.638	0.9997	0.9998	0.9995	295.2	39.04	0.0721
	80%	2.054	21.70	1.491	0.9997	0.9997	0.9994	294.7	51.93	0.0841
	100%	2.224	27.03	1.218	0.9997	0.9997	0.9994	294.3	64.75	0.0927

And, this is the performance analysis and comparison between 28 and 56 pulse AC-DC converter at different loading conditions.

(Refer Slide Time: 25:35)



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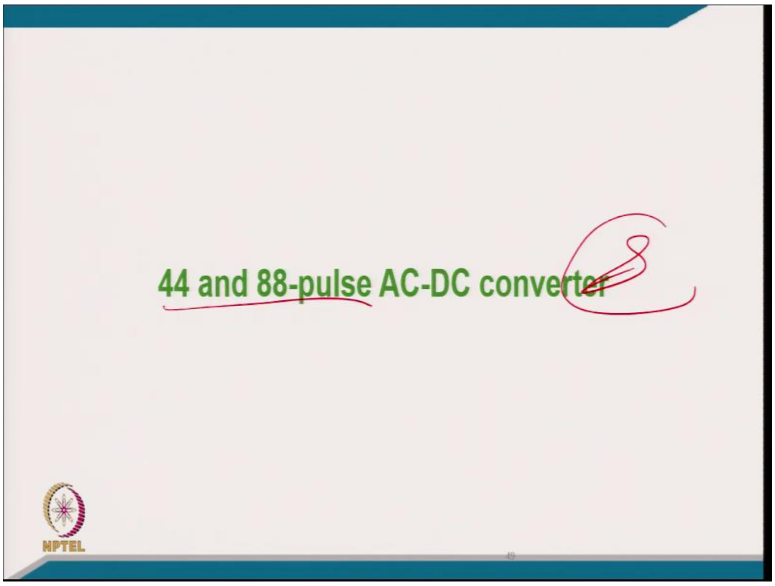

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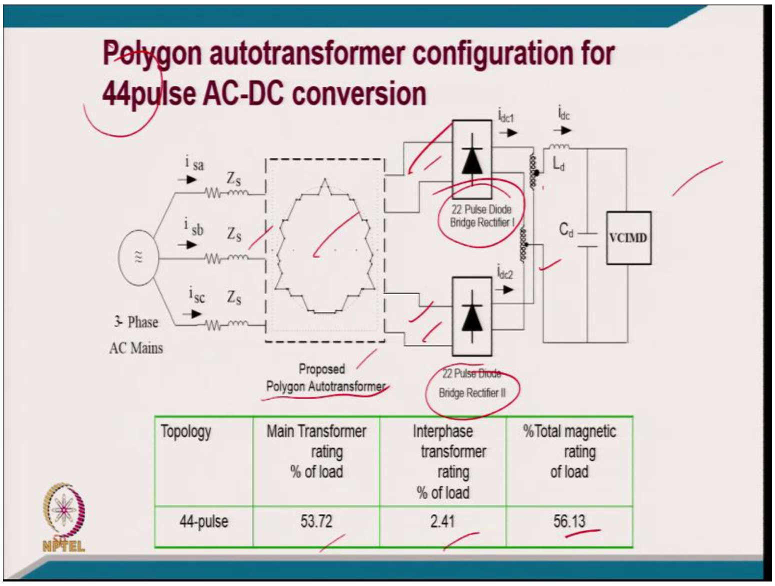

Now, coming to another set of non-conventional multipulse converter i.e., 44 and 88-pulse AC-DC converters. And, this is what we do here, we convert virtually here three-phase input supply into 11-phase supply.

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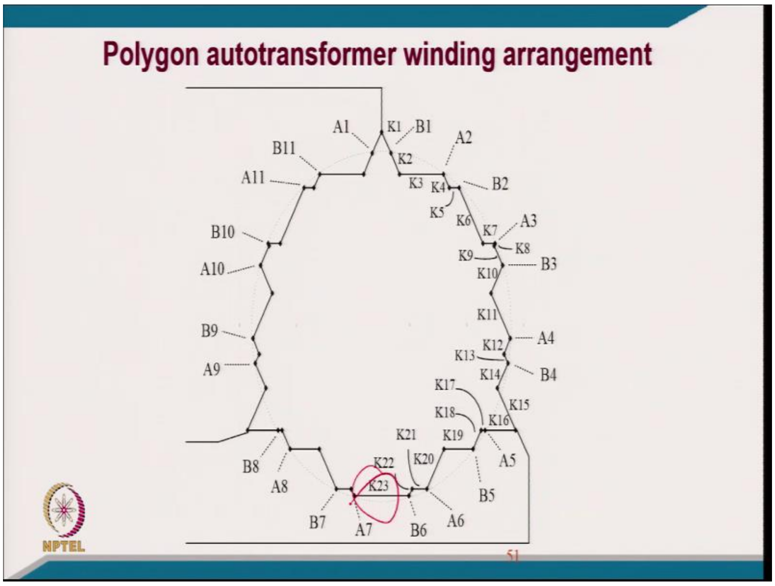

And, this is the how the connections of polygon autotransformer windings are carried out.

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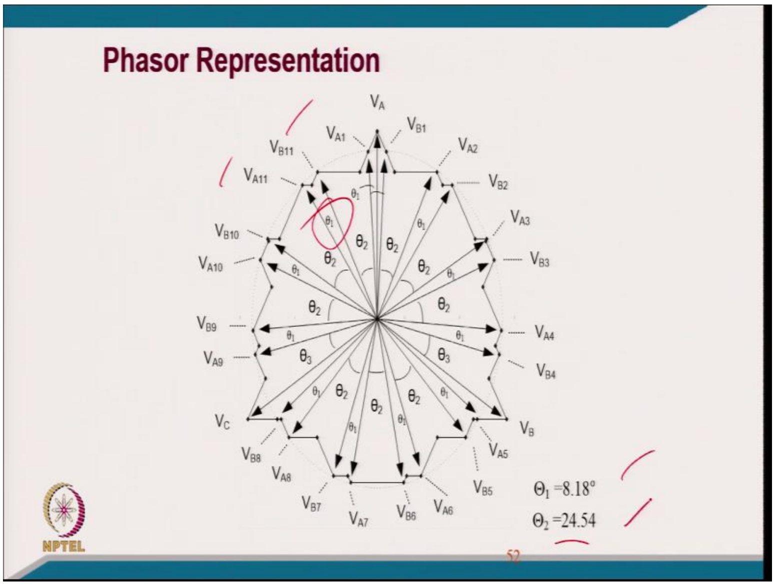
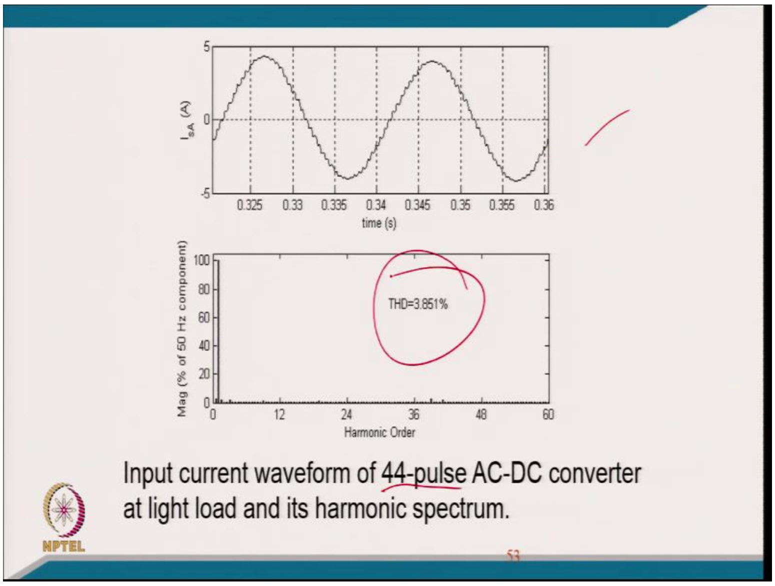


And, this is the corresponding phasor diagrams.

(Refer Slide Time: 27:39)



Input current waveform of 44-pulse AC-DC converter at light load and its harmonic spectrum.

So, the THD corresponding to 44-pulse you are getting order of 3.851 percent.

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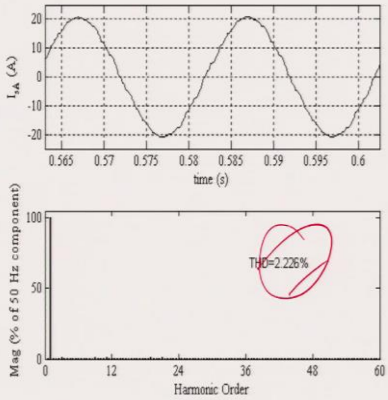

Input current waveform of 44-pulse AC-DC converter at full-load and its harmonic spectrum.

And, typically for your load full load conditions you are getting typically of 2.26 percent.

(Refer Slide Time: 27:54)

Comparison of power quality parameters of the load fed from isolated 44/88-pulse AC-DC converters

Sr. No.	Topology	Load	THD V_{ac} (%)	AC Mains Current I_{ac} (A)	THD of I_{ac}(%)	DF	DPF	PF	DC Voltage (V)	Load Current I_{dc} (A)	RF (%)
1	44-pulse	20%	0.8708	5.959	2.646	0.9996	0.9991	0.9987	302.1	13.47	0.08
		40%	1.213	10.41	2.311	1.0000	0.9997	0.9997	301.7	25.91	0.09
		50%	1.5	14.44	2.02	0.9999	0.9997	0.9996	301.2	33.53	0.09
		60%	1.644	17.26	1.85	0.9997	0.9998	0.9995	300.9	40.18	0.1028
		80%	1.82	22.31	1.59	0.9997	0.9995	0.9992	300.1	52.81	0.125
		100%	1.94	28.34	1.34	0.9997	0.9993	0.999	299.7	66.55	0.1415
2	88-pulse	20%	0.5094	5.951	1.392	0.9999	0.9992	0.9991	301.6	13.44	0.06252
		40%	0.741	10.32	1.387	0.9998	0.9996	0.9994	300.9	25.82	0.0911
		50%	1.061	14.4	1.38	0.9998	0.9997	0.9995	300.4	33.39	0.1174
		60%	1.302	17.21	1.34	0.9998	0.9991	0.9989	299.8	40.11	0.1311
		80%	1.519	22.26	1.302	0.9998	0.9987	0.9985	299.2	52.76	0.148
		100%	1.706	28.22	1.270	0.9998	0.9984	0.9982	298.4	66.13	0.1651

And, this is the comparison of power quality parameters of the load fed from isolated 44/88 pulse AC-DC converters under different loading conditions.

(Refer Slide Time: 28:18)

Comparison of power quality parameters of the load fed from different isolated converters

Sr. No.	Topology	%THD V_{ac}	% THD of I_{ac}, at		DF		DPF		PF		DC Voltage (V)	
			Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load
1	6-pulse	4.056	24.81	27.93	.9815	.9943	.9698	.9630	.9519	.9575	279.2	294.4
2	12-pulse	3.278	9.730	12.19	.9915	.9987	.9947	.9925	.9863	.9912	283.7	288.7
3	18-pulse	1.487	2.776	5.360	.9776	.9897	.9995	.9986	.9771	.9883	289.1	297.3
4	20-pulse	3.091	4.874	6.917	.9952	.9980	.9984	.9975	.9936	.9955	300.0	302.9

(Refer Slide Time: 28:36)

Sr. No.	Topology	%THD V_{ac}	% THD of I_{ac}, at		DF		DPF		PF		DC Voltage (V)	
			Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load
5	28-pulse	3.495	3.76	5.12	.9987	.9986	.9990	1.000	.9977	.9986	293.7	295.9
6	40-pulse	1.350	2.060	2.533	.9919	.9979	.9997	.9996	.9916	.9975	291.7	303.1
7	44-pulse	1.94	1.34	2.646	.9997	.9996	0.9993	0.9991	0.9999	0.998	299.7	302.1
8	56-pulse	2.224	1.218	2.23	.9997	.9997	.9997	1.000	.9994	.9997	294.3	296.2
9	88-pulse	1.706	1.276	1.392	.9999	.9998	0.9984	0.9992	0.9982	0.9991	298.4	301.6

This is the comparative analysis of power quality parameters of the load fed from different isolated converters.

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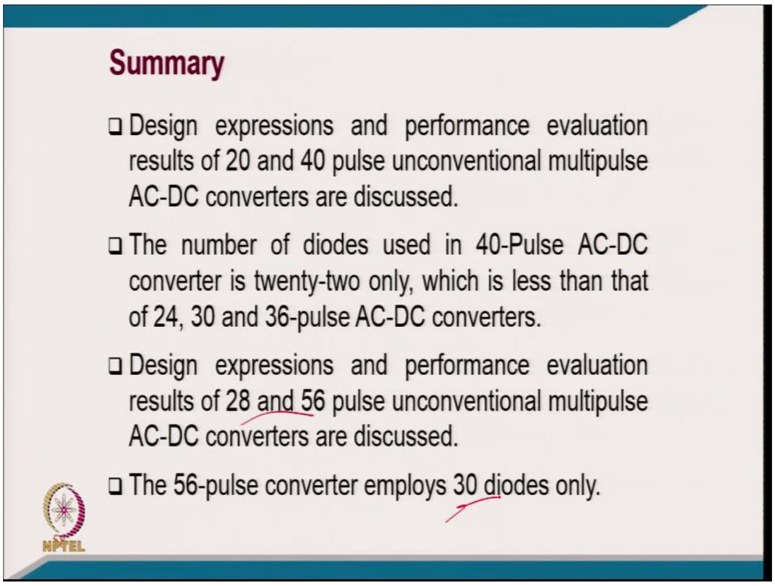

So, coming to the conclusion of this non-conventional multipulse converter. Design expression and performance evaluation of 20 and 40-pulse unconventional multipulse AC-DC converters are discussed. The number of diodes used in 40-pulse converters is 22 only which is less than even 24 or 30 or 36-pulse converter.

And, design expressions and performance evaluation of 28 and 56-pulse unconventional multipulse converters are discussed. And, the 56-pulse converter employs only 30 diodes; 28 plus 2 means 30 diode.

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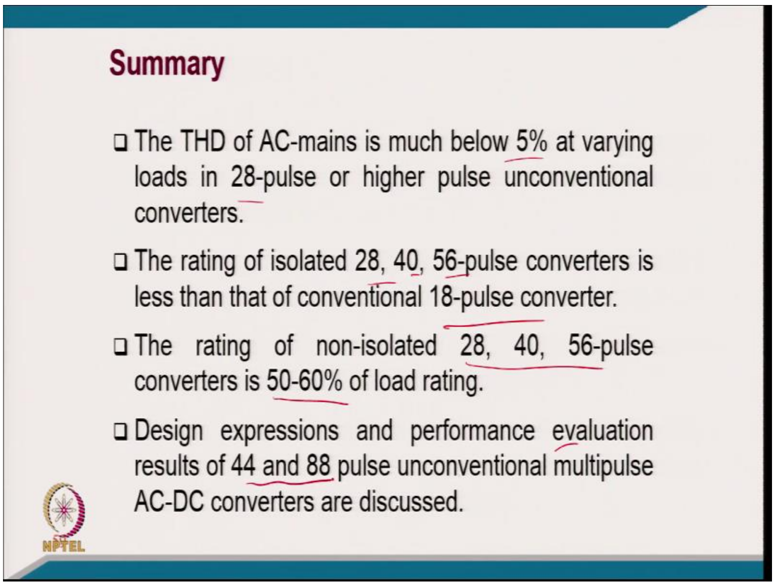

And, the THD at ac mains is less than 5 percent at varying load in 28-pulse converter or higher pulse unconventional converters.

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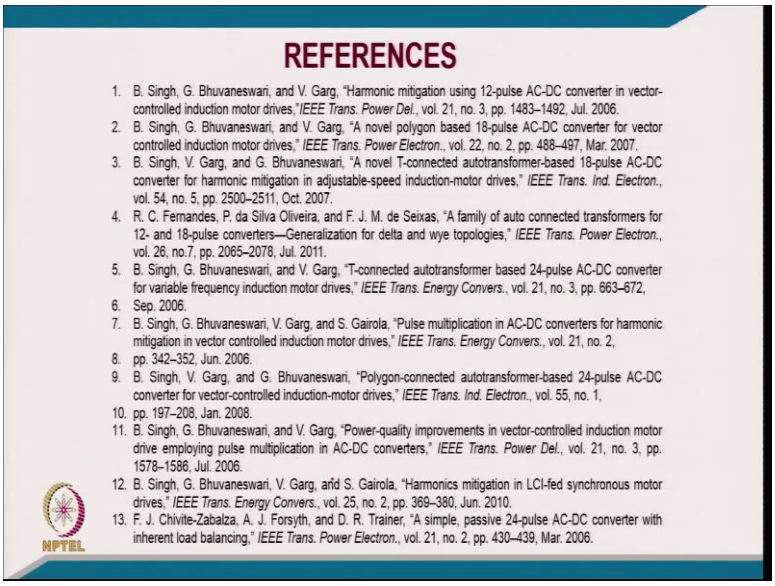

And, these are the typical references which we have referred.

Thank you like I mean.