Zigzag Connected Autotransformer Based 12, 24 & 36- Pulse Rectifiers

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Abstract **- The conversion of AC power to DC power causes harmonics in the input current. By increasing the number of pulses in multi-pulse converters, the Total Harmonic Distortion (THD) in input current can be reduced, and other performance parameters can also be improved. This paper briefly analyzes the pulse multiplication techniques to get 12-pulse, 24-pulse and 36-pulse controlled converters, having a zigzag connected auto-transformer. The effect of increasing the number of pulses, on the performance of AC to DC converters is analyzed by Simulation in MATLAB software. The comparison in these configurations is presented to indicate their effectiveness.**

Keywords- **Multipulse converters, Zigzag Auto-transformer, Pulse multiplication, Power quality, Multipulse AC-DC converter, THD.**

I. INTRODUCTION

The harmonics in the input current and output voltage of conventional 12-pulse uncontrolled rectifiers can be reduced by using tuned passive filters. However, these filters are bulky and lossy. Moreover, some applications have stringent power quality specifications and it is mandatory to use a higher pulse AC-DC converter system. Therefore, it is recommended that a higher pulse AC-DC converter must be used so that IEEE-519 standard requirements are met.

II. ZIGZAG TRANSFORMER

A zigzag connected or phase shifting auto-transformer is a special purpose transformer [1-4], connected such that its output is the phasor sum of two phases offset by 120°. For doing this, each winding on each phase has two halves, which help this connection to suppress all triplen harmonics e.g. 3rd, 9th, 15th, etc.

The zigzag connected auto-transformer is suitable for 12-pulse AC-DC conversion which employs two six-pulse bridges, connected in parallel. But to obtain 24, 36-pulse or higher pulse number AC-DC converter from 12-pulse AC-DC converter, pulse multiplication is used [1] and this is achieved using IPR, tapped with two or three thyristors or diodes.

The Zigzag transformer connection has an advantage over other connections that in pulse multiplication process there is no need of Zero Sequence Blocking Transformer (ZSBT) [2]. Hence it is a cost effective approach along with compact size and improved reliability.

A. ZIGZAG CONNECTED AUTO-TRANSFORMER FOR 12-PULSE AC-DC RECTIFICATION

In multipulse AC-DC converters, the phase shift required between the set of 3-phases for proper harmonic elimination is given by

Phase Shift = 60o/ (Number of six-pulse converters (1)

In multipulse converters, for achieving 12-pulse ac-dc conversion, the required phase shift may be either 30o or ±15o with respect to supply voltages. Fig.1 shows the winding connection diagram and the phasor diagram for zigzag connected auto-transformer. Here two sets of three phase voltages produced which are displaced from each other ±15o from input AC voltage. These voltages can be realized by the following relationships:

$$V_A = V\angle 0^\circ, \quad V_B = V\angle -120^\circ, \quad V_c = \angle 120^\circ$$

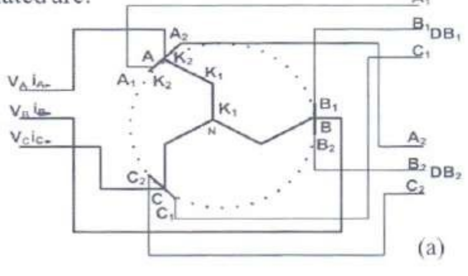
$$V_{AB} = \sqrt{3}V\angle 30^\circ, \; V_{BC} = \sqrt{3}V\angle -90^\circ, \; V_{CA} = \sqrt{3}V\angle 150^\circ \quad (2)$$

For the proposed 12-pulse transformer configuration the output voltage can be expressed using phasor diagram as follows:

$$V_{A1} = K_1(V_{AB} - V_{CA}) - K_2 V_{BC} \quad (3)$$

$$V_{A2} = K_1(V_{AB} - V_{CA}) + K_2 V_{BC} \quad (4)$$

The values of these constants K1 and K2 determine the winding turns as a fraction of the input phase voltage for the 12-pulse AC-DC converter. The values of K1 and K2 calculated are:



(a)

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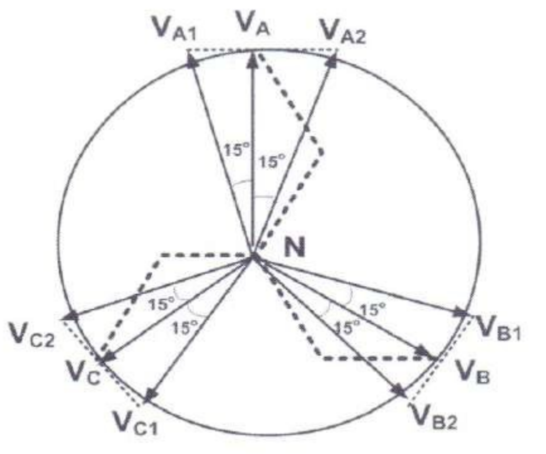


(b)

Fig.1 (a) Winding connection diagram for auto-transformer. (b) Phasor diagram of voltages for 12-pulse AC-DC converter

$K_1 = 0.5773$, $K_2 = 0.2679$ (5)

The VA rating of a transformer depends on two quantities that are the voltage across each winding and the current through the windings. The winding voltages determine the core size while the currents determine the conductor size and, hence, these two quantities are required to determine its VA rating. The VA rating of these transformers is calculated as:

$$\text{VA rating} = 0.5\ \Sigma\ (V_k\ I_k) \quad (6)$$

where, Vk and Ik are the root-mean-square value of the voltage across and the current through the kth winding. Above equation has been used to determine the rating of the autotransformer and the Interphase Reactor (IPR) used in the proposed 24-pulse and 36-pulse controlled AC-DC converters.

A. A 24-PULSE AC-DC CONVERTER

In this method of multipulse AC-DC conversion, a small rating zigzag wound autotransformer and an Interphase Reactor (IPR) tapped with two thyristors are used. This is shown in Fig.2.

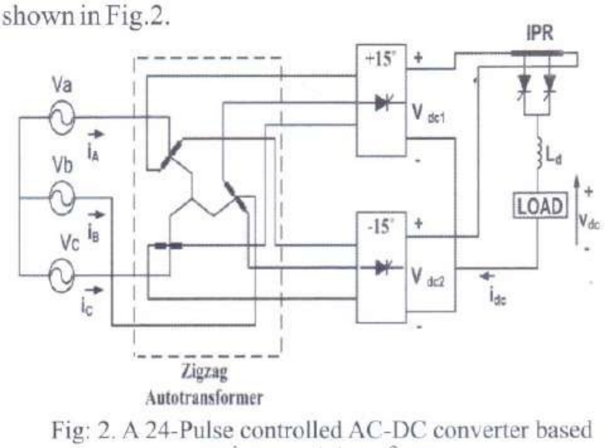


Fig: 2. A 24-Pulse controlled AC-DC converter based on zigzag autotransformer

The zigzag connection based auto-transformer is suitable for 12-pulse AC-DC conversion which employs two six-pulse bridges, connected in parallel. But to obtain 24-pulse AC-DC converter from 12-pulse AC-DC converter pulse multiplication is used, and this is achieved using an IPR, tapped with two thyristors as shown in Fig.2. The schematic diagram of interphase reactor (IPR) tapped with two thyristors, used in 24-pulse controlled converter is shown in Fig.3. Here the calculated value for N1 and No are 25.43 and 49.14 respectively.

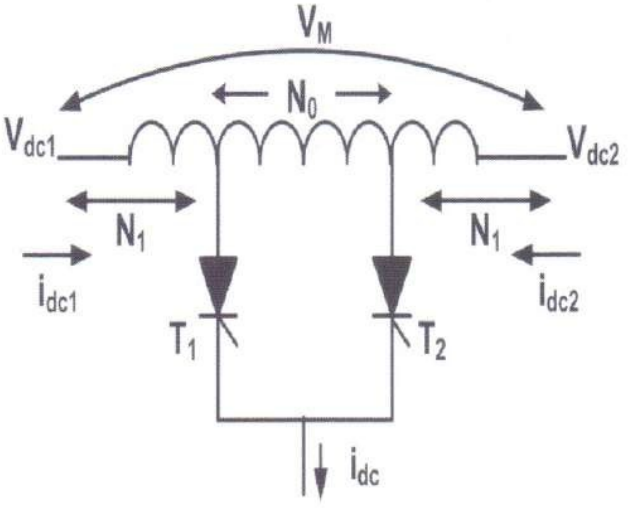


Fig.3. IPR tapped with two Thyristors

B. A 36-PULSE AC-DC CONVERTER

In this configuration of multipulse AC-DC conversion to obtain 36-pulse controlled AC-DC converter, pulse multiplication is carried out with the help of an IPR tapped with three thyristors. Fig.4 shows the schematic diagram of 36-pulse controlled AC-DC converter in which a zigzag wound autotransformer and an IPR tapped with three thyristors is used.

Fig. 5 shows the schematic diagram for the three thyristor tapped IPR, used in 36-pulse AC-DC converter for pulse multiplication to obtain 36 pulsations at the output voltage.

For the IPR the calculated value for N3 and N4 is given as 33.23 and 16.77 respectively.

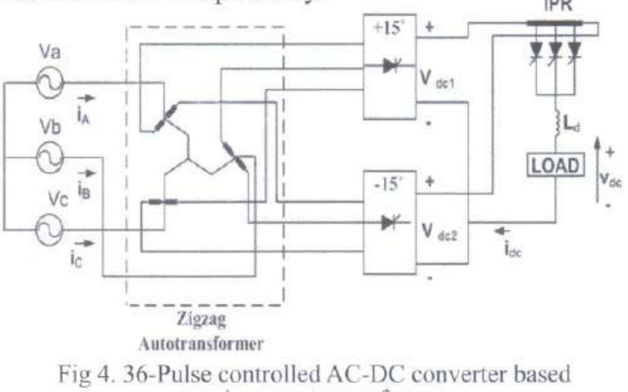


Fig 4. 36-Pulse controlled AC-DC converter based on zigzag autotransformer

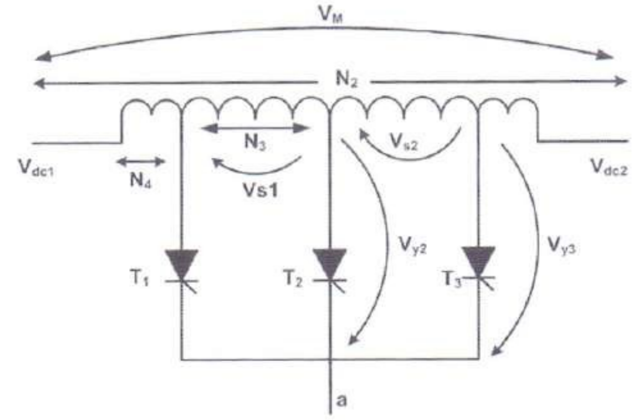


Fig 5 IPR tapped with three Thyristors

III. MATLAB BASED SIMULATION

The proposed 12, 24 and 36–pulse AC-DC controlled converters are simulated in MATLAB environment employing SIMULINK and Sim Power System toolboxes. Fig.6 shows

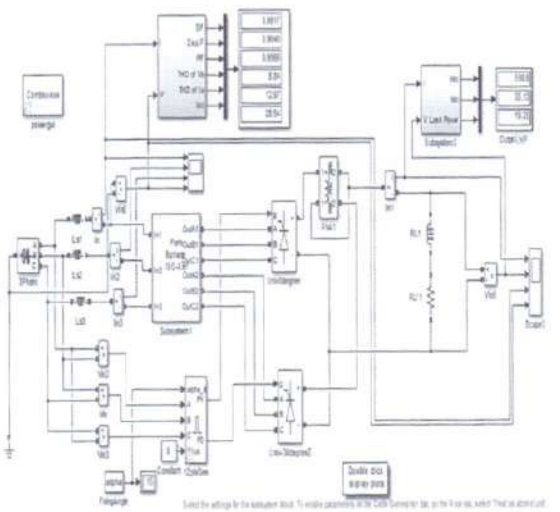


Fig.6. Zigzag connected 12-pulse converter developed in MATLAB/ SimPower system toolbox.

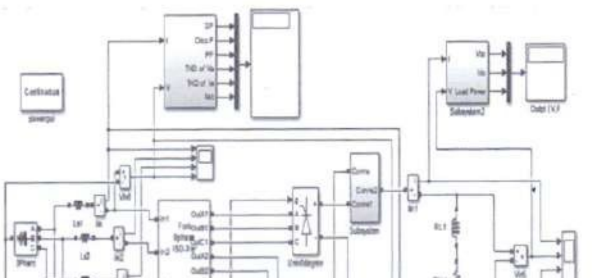


Fig.7. Zigzag connected 24 &36 pulse converter developed in MATLAB/ SimPower system toolbox

the MATLAB model of a 12-pulse converter and Fig.7 shows the MATLAB model of 24 and 36-pulse converters.

In the Fig.8 the MATLAB model for zigzag connected auto-transformer is shown, which is used in the 12, 24-pulse and 36 -pulse AC-DC converters. It shows the basic connection arrangement used in the transformer.

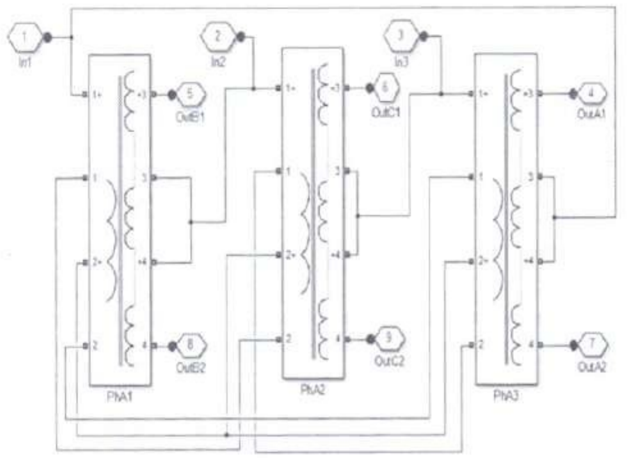


Fig.8. MATLAB model of zigzag connected auto-transformer, for the 24-pulse and 36 -pulse AC-DC converter simulation.

IV. RESULTS

The following figures show various waveforms and THD spectrums obtained from the MATLAB simulation for various input and output quantities for different values of firing angle alpha for12-pulse, 24-pulse and 36-pulse converters.

At alpha= 15^0

As the figures 9-14 shows various input and output waveforms and their THD spectrums at different firing angles for the proposed three topologies. From these figures it is clear that as the number of pulsations is increased at the output, the amount of THD introduced in the supply current is reduced and approaches the IEEE standards.

V CONCLUSIONS

It has been observed that the proposed 24-pulse and 36-pulse controlled AC-DC converters are capable of increasing the pulse number using thyristors tapped IPR. But from the simulation results listed in the Table-1, it is concluded that the 36- pulse AC-DC converter is found more capable of minimizing the THD and improving input AC current waveform as well as output DC voltage simultaneously for a wide range of firing angle alpha. The power factor has also improved in comparison to12 AC-DC converter at varying.

Table 1
COMPARISON OF POWER QUALITY PARAMETERS OF 12-PULSE, 24-PULSE AND 36-PULSE AC-DC CONTROLLED CONVERTERS FEEDING LOAD AT VARIOUS FIRING ANGLES

Topology	Firing Angle (degrees)	THD of V_A(%)	AC mains current I_A(A)	THD of I_A (%)	Distortion Factor	Displace-ment Factor	Power Factor	DC voltage (V_{dc})	Load current I_{dc} (A)	Load power (kW)
12	10	7.613	29.06	12.22	.9926	.9811	.9739	561.6	35.81	20.11
	15	8.840	28.54	12.97	.9917	.9646	.9566	550.8	35.13	19.35
	30	11.49	25.64	14.07	.9902	.8709	.8624	494.0	31.50	15.56
	60	11.28	14.85	15.11	.9888	.5059	.5003	285.4	18.20	5.196
24	10	5.653	29.77	5.438	.9985	.9811	.9797	569.3	36.30	20.67
	15	5.758	29.22	5.758	.9983	.9644	.9628	558.3	35.61	19.88
	30	9.290	26.21	6.497	.9979	.8704	.8686	500.4	31.91	15.97
	60	9.578	15.14	7.305	.9973	.5052	.5038	288.6	18.41	5.314
36	10	3.937	29.79	5.094	.9987	.9756	.9744	567.8	36.21	20.56
	15	4.919	29.32	4.133	.9991	.9607	.9599	558.4	35.62	19.89
	30	7.025	26.28	4.153	.9991	.8670	.8662	500.5	31.92	15.98
	60	7.512	15.16	4.770	.9989	.5023	.5018	288.7	18.41	5.314

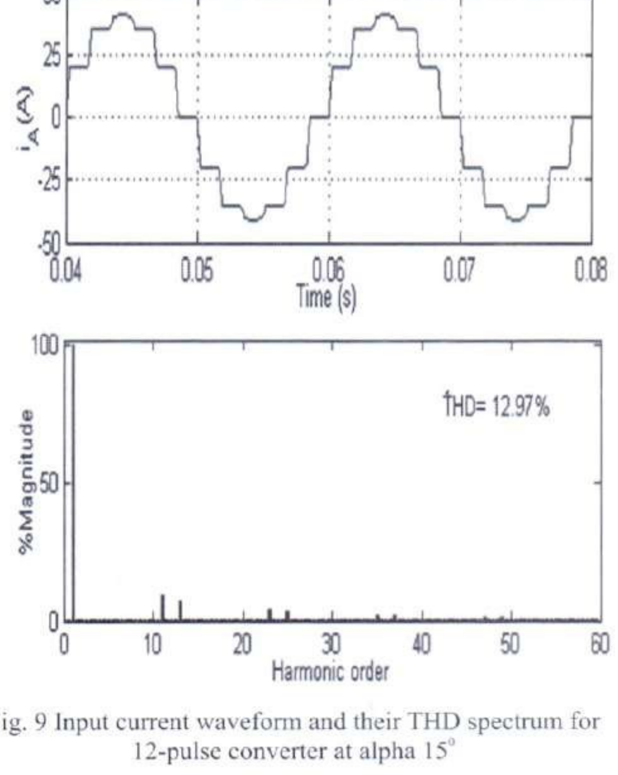


Fig. 9 Input current waveform and their THD spectrum for 12-pulse converter at alpha 15°

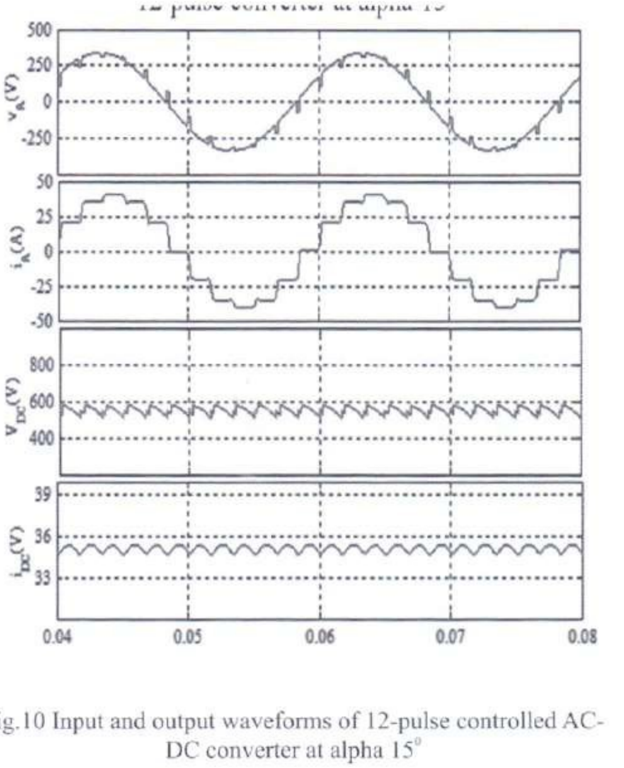


Fig.10 Input and output waveforms of 12-pulse controlled AC-DC converter at alpha 15°

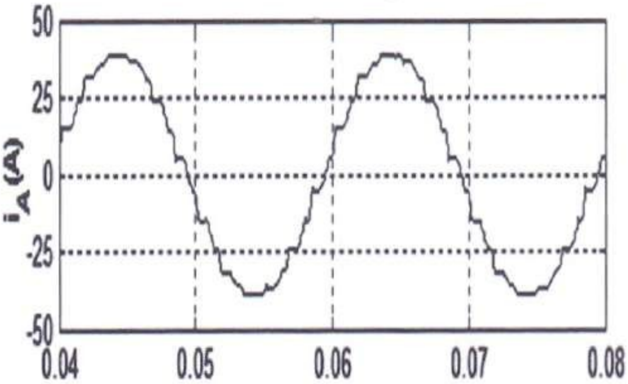


Fig. 11 Input current waveform and their THD spectrum for 24-pulse converter at alpha 15°

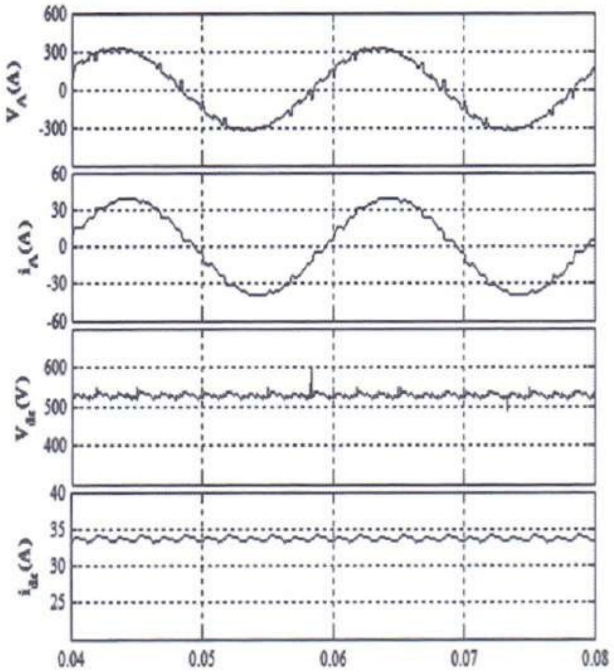
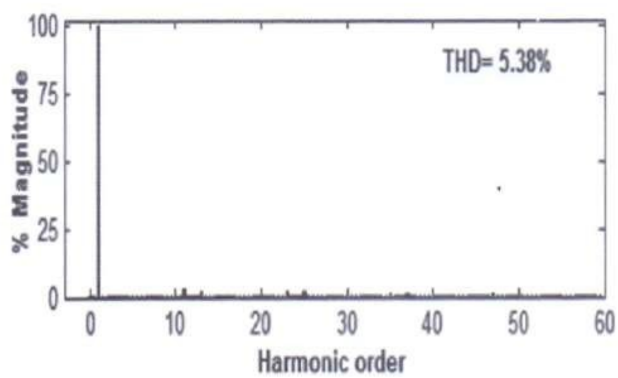


Fig.12 Input and output waveforms of 24-pulse controlled AC-DC converter at alpha 15°



firing angles. The resulting 36-pulse converter system meets all IEEE-519 Standard requirements, and total harmonic distortion of input current remains below 5% for a wide range of operating firing angle.

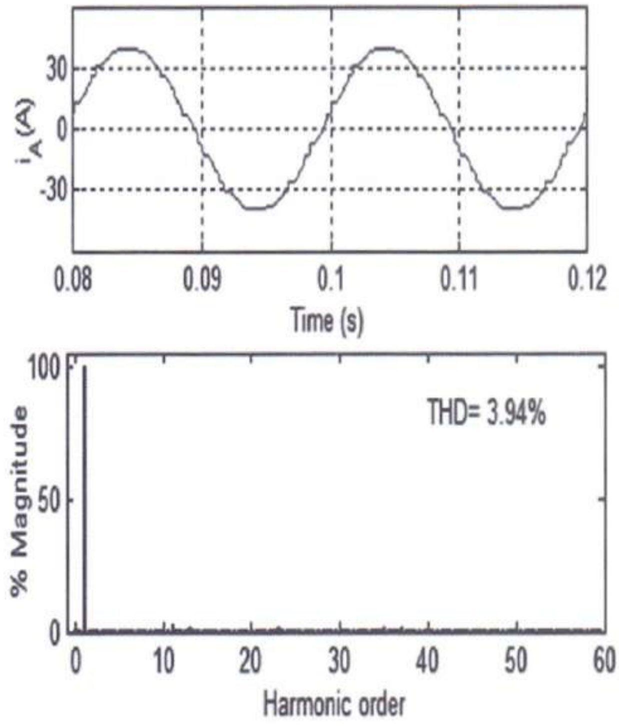


Fig.13 Input current waveform and their THD spectrum for 36-pulse converter at alpha 15°

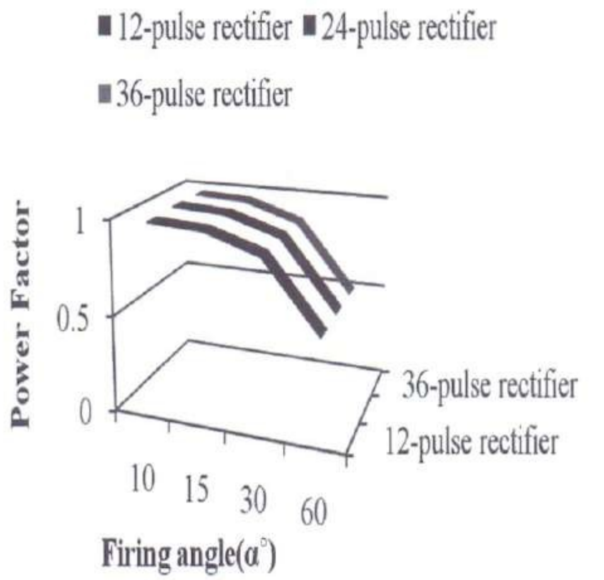


Fig.15. Variation of Power Factor with varying firing angle for proposed topologies

The THD of 24-pulse rectifier also gives a quite satisfactory performance at higher loads, but the 12-pulse converter is not as efficient as remaining two converters. All three configurations do not require ZSBT for pulse multiplication, and therefore these are cost effective. In controlled configurations, the minimum value of firing angles for 24-pulse is 5o while for 36-pulse it is 10°.

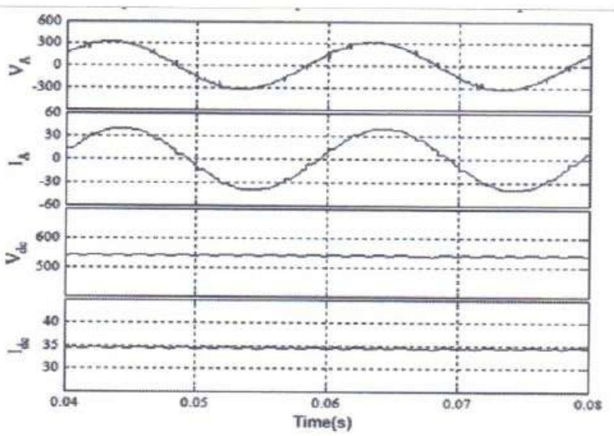


Fig.14. Input and output waveforms of 36-pulse controlled AC-DC converter at alpha 15°.

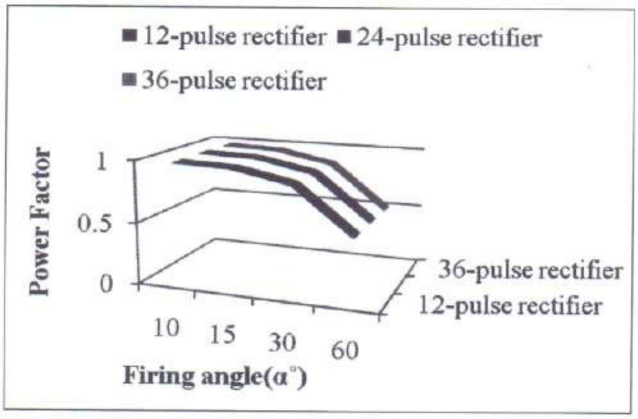


Fig.15. Variation of Power Factor with varying firing angle for proposed topologies

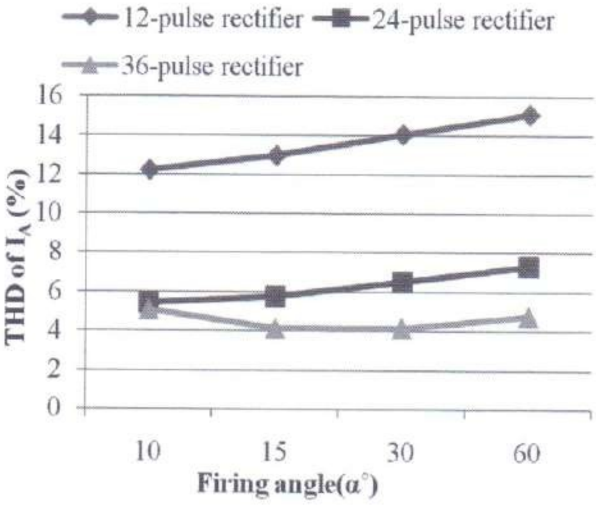


Fig.16. Variation of THD of supply current at different firing angles for proposed topologies.

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