MULTI PULSE RECTIFIER USING DIFFERENT PHASE SHIFTING TRANSFORMERS AND ITS THD COMPARISON FOR POWER QUALITY ISSUES

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Abstract - ***The converters which are also known as rectifiers are generally fed from three phase ac supply have problems of power quality in terms of harmonics injected into the supply which cause poor power factor, ac voltage distortion and rippled dc outputs. To eradicate these problems, multipulse converters can be used. Multi pulse converters are converters providing more than six pulses of DC voltage per cycle or the converter is having more steps in AC input current than that of six pulse rectifier supply current. In this paper multipulse converter with 6, 12, 18, 24 and 36 pulse rectifier are designed using different topologies of three phase star-delta, delta-star, star-star, delta-delta, and ziz-zag connection of transformer for different phase shifts. It has been proved that these topologies provide less harmonics and good voltage regulation with proper comparisons of their THD levels.***

Key Words: *phase shifting transformers, multi pulse rectifier, total harmonic distortions (THD), fast Fourier transforms (FFT).*

1. INTRODUCTION

Now days the harmonic distortion is the big issue for the power quality, harmonics create a serious problem in the electronics world. The harmonics in the power system cause serious problem due to the wide application of the power electronics equipments based industrial process in which the AC-DC converters are normally used. The power factor and the harmonic distortion can be improved by increasing the pulse number of AC-DC converters. This harmonic current injection is mainly due to the non linear nature of loads connected to electrical utility, e.g. industrial electrical equipment. The low power factor of the electric installation is responsible for a series of problems caused in electrical system. This results in increased losses in conductor, error introduced in measuring equipment, malfunction of other equipment connected to mains due to distortion of line voltage.

Many techniques have been proposed to solve the harmonic current problem like active filtering (STATCOM) to supply load reactive power and harmonics. Passive Current Shaping method include both the utilization of harmonic taps to attenuate certain frequencies as well as multiple configuration like 6, 12, 18, 24, 36, pulse diode/thyristors (uncontrolled/controlled) configuration.

Some applications have stringent power quality specification, so it is suggested that higher pulse AC-DC converter must be used to meet standard requirements. The harmonics in input current and output voltage of conventional multi pulse controlled rectified fed from delta/star transformer can be reduced by using filters. But these filters are bulky and loss. Moreover some applications have stringent power quality specification and it is advisable to use multi pulse AC-DC converter system configuration. Therefore, it is suggested that higher pulse AC-DC converters have to be used.

The multi pulse converter has different connections possible including series/parallel in which each rectifier are fed by phase shifted transformer to shaped secondary windings‟ voltages of a transformer to shape the primary current close to sinusoidal. Increasing the number of rectifiers raises the number of steps in the primary current wave form and produces a sinusoidal shaped supply current flowing into the transformer primary winding. For harmonic mitigation, multi pulse uncontrolled converters are very popular due to the absence of any control system for the power diodes. However control of output voltage is not possible. On the other hand controlled rectifier requires control circuit so the design is complicated and the cost increases, too.

When reactive power compensation in the form of passive power factor improving capacitors are used with nonlinear loads, resonance conditions can occur that may result in even higher levels of harmonic voltage and current distortion thereby causing equipment failure, disruption of power services and fire hazards in extreme conditions. To refine the above said defects the project incorporate designing an multi pulse AC-DC converter using Zig-Zag connected transformer which is able to reduce the total harmonic distortion in input AC mains at varying loads within the limits i.e. less than 5% and also improving the power quality. The designed AC-DC converter system is modeled and simulated in MATLAB to demonstrate its power quality improvement at AC mains.

2. PHASE SHIFTING TRANSFORMERS

Phase shifting transformer provides a three main functions like required phase displacement between primary and secondary line-line voltage for harmonic cancellation, proper secondary voltage, and an electrical isolation between the rectifiers and the utility supply.

Phase shifting transformers are classified in two categories: Y/Z and Δ/Z where the primary winding can be connected in to Y or Δ where the secondary winding is normally connected in Z. Both configurations can be equally used in multi pulse rectifier. And also other transformer connections can be used in multi pulse rectifier like Y/Y, Y/Δ, Δ/Y, and Δ/Δ.

2.1 Y/Y & Y/Δ connection of transformer:

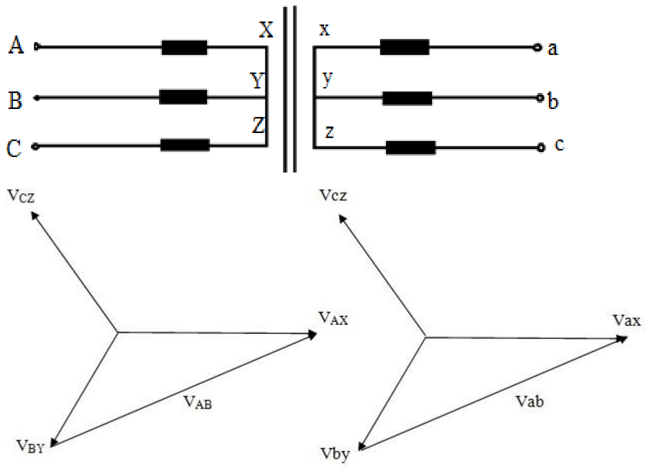
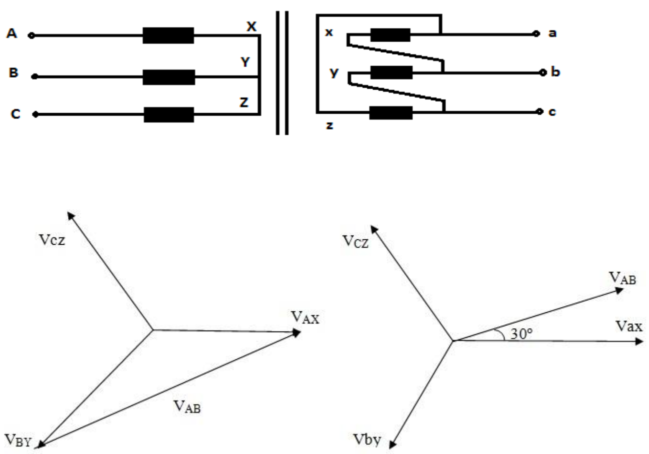


Figure 1 Phasor Diagram of Y/Y transformer



2.2 Y/Z -1 phase shifting transformer:

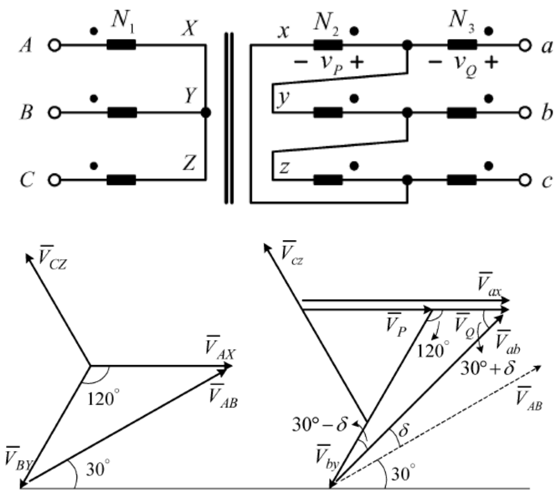


Figure 2: Phasor diagram of Y/Z-1 transformer

2.3 Y/Z-2 phase shifting transformer:

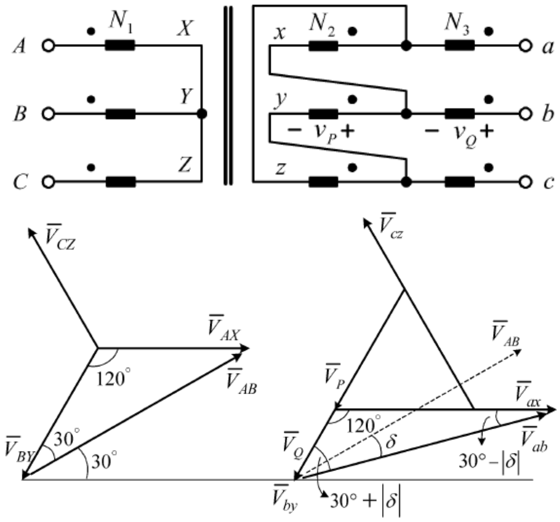


Figure 3: Phasor Diagram of Y/Z-2 transformer

Table 1 Turns Ratio for Y-Z Transformer

Y/Z-1 (δ)	**Y/Z-2 (δ)**	$\frac{N2}{N1+N}$	$\frac{N_1}{N_3+N_2}$	**Applications**
0°	0°	1.0	$1.0\,\frac{V_{AB}}{V_{ab}}$	12,18 and 24- pulse rectifiers
15°	-15°	0.366	$0.707\,\frac{V_{AB}}{V_{ab}}$	24-pulse rectifiers

20°	-20°	0.277	$0.653\frac{V_{AB}}{V_{ab}}$	18-pulse rectifiers
30°	-30°	0	$0.577\frac{V_{AB}}{V_{ab}}$	12 and 24-pulse rectifier

2.3 Δ/Z-1 phase shifting transformer:

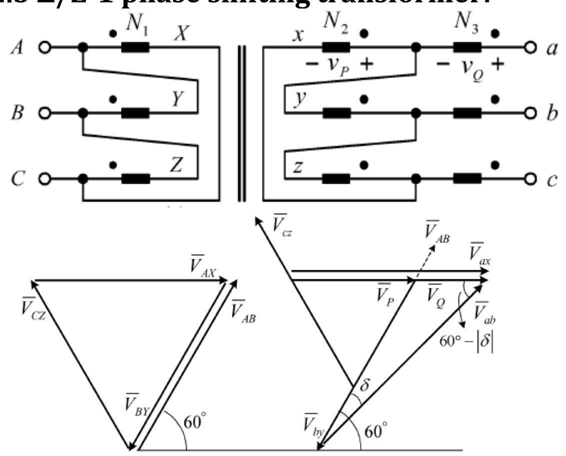


Fig- 4: Phasor diagram of Δ/Z-1 transformer

2.4 Δ/Z-2 phase shifting transformer:

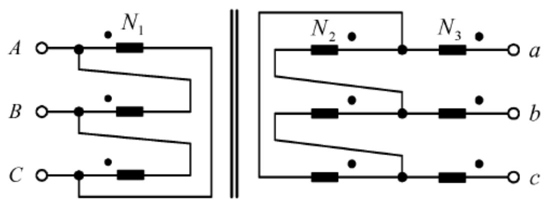


Fig- 5 connection diagram for Δ/Z-2 transformer

Table 2 Turns Ratio For Δ/Z Transformer

Zigzag Transformer	(δ)	$\frac{N_3}{N_3+N_2}$	$\frac{N_1}{N_2+N_3}$	Applications
Δ/Z_1	0°	0	$1.0\frac{V_{AB}}{V_{ab}}$	12,18 and 24-pulse rectifiers
	-15°	0.366	$1.225\frac{V_{AB}}{V_{ab}}$	24-pulse rectifiers
	-20°	0.532	$1.347\frac{V_{AB}}{V_{ab}}$	18-pulse rectifiers
	-30°	1.0	$1.732\frac{V_{AB}}{V_{ab}}$	12 and 24-pulse rectifier
Δ/Z_2	-40°	0.532	$1.347\frac{V_{AB}}{V_{ab}}$	18-pulse rectifiers
	-45°	0.366	$1.225\frac{V_{AB}}{V_{ab}}$	24-pulse rectifiers
	-60°	0	$1.0\frac{V_{AB}}{V_{ab}}$	18-pulse rectifiers

Harmonic cancelations:

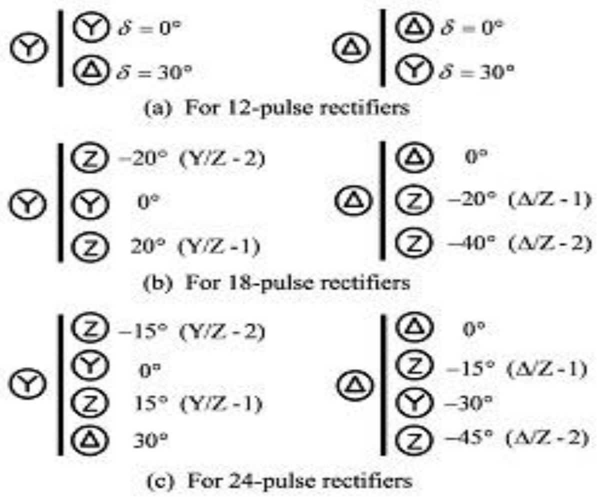


Fig- 6: Examples of phase-shifting transformers for multi pulse rectifiers

3. MULTIPULSE RECTIFIER

The main feature of the multi pulse rectifier lies in its ability to reduce the line current harmonic distortion. As the pulse number increases, the harmonics present in the input decreases and the Total Harmonic Distortion (THD) reduces. This is achieved by the phase shifting transformer, through which some of the low-order harmonic currents generated by the six-pulse rectifiers are canceled. In general, the higher the number of rectifier pulses, the lower the line current distortion is. The rectifiers with more than 30 pulses are seldom used in practice mainly due to increased transformer costs and limited performance improvements.

3.1 Six pulse rectifier:

The six pulse rectifier is also popularly known as the three phase bridge rectifier which uses diodes for converting ac to dc. Power circuit diagram for a 3-phase bridge rectifier using six diodes is shown in the figure. The diodes are arranged in three legs. Each leg has two series-connected diodes. Upper diodes D1, D3, D5 constitute the positive group of diodes.

The lower diodes D2, D4, D6 form the negative group of diodes. The three-phase transformer feeding the bridge is connected in delta-star. This rectifier is also called 3 phase 6-pulse diode rectifier, 3-phase full wave diode rectifier.

Positive group of diodes conduct when these have the most positive anode. Similarly, negative group of diodes would conduct if these have the most negative anode. In other words, diodes D1, D3, D5, forming positive group, would conduct when these experience the highest positive voltage. Likewise, diodes D2, D4, D6 would conduct when these are subjected to the most negative voltage. The figure of 6 pulse diode rectifier is shown in figure [7].

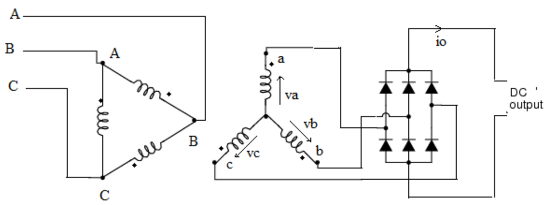


Fig- 7: six pulse diode rectifier

It is seen from the source voltage waveform vs of fig. (A) From ωt=30°to 150°, voltage va is more positive than the voltages vb, vc. Therefore, diode D1 connected to line 'A' conducts during the interval ωt = 30° to 150°.

Likewise, from ωt=150° to 270°, voltage Vb is more positive as compared to va, vc; therefore, diode D3 connected to line 'B' conducts during this interval. Similarly, diode D5 from the positive group conducts from ωt = 270° to 390° and so on. Note also that from ωt = 0 to 30°, vc is the most positive, therefore, diode D5 from the positive group conducts for this interval. Conduction of positive group diodes is shown in fig (B) as D5, D1, D3, D5, D1, etc

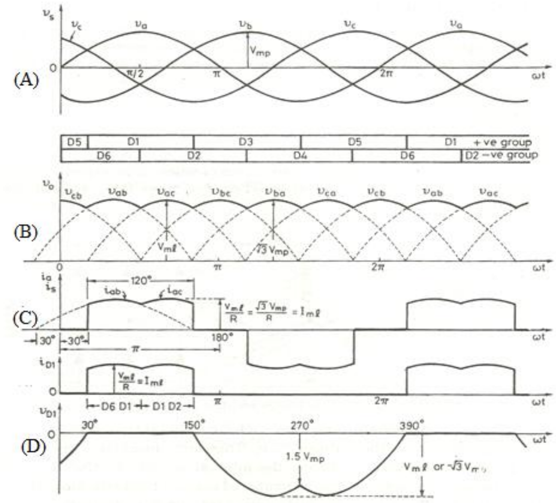


Fig-8: I/P, O/P voltage and current wave forms

Voltage v_c is the most negative from ωt = 90° to 210°. Therefore, negative group diode D2 connected to line 'c' conducts during this interval. Similarly, diode D4 conducts from 210° to 330° and diode D6 from 330° to 450° and so on. Not also that from ωt = 0° to 90°, vb is the most negative, therefore diode D6 conducts during this interval. Conduction of negative group diodes is shown as D6, D2, D4, D6, etc. in fig (B).

During the interval ωt = 0° to 30°, it is seen from fig (B) that diode D5 and D6 conduct. The figure shows that conduction of D5 connects load terminal P to line terminal c; similarly, conduction of D6 connects load terminal Q to line terminal b. As a result, load voltage is v_{pq} = v_0 = line voltage vcb from ωt = 0° to ωt = 30°. Likewise, during ωt = 30° to 90°, diodes D1 and D6 conduct. Conduction of diode D1 connects P to a and D6 to b.

Therefore, load voltage during this interval is v_0 = line voltage v_{ab}. Similarly, for interval 90° to 150°, diodes D1 and D2 conduct and v_0 = line voltage vac; for interval 150° to 210°, diodes D3 and D2 conduct and v_0 = line voltage v_{bc} and so on. Output, or load, voltage waveform is drawn by a thick curve in fig (C).

Average value of load voltage,

$$V_0 = \frac{1}{\text{periodicity}} \int_{\alpha 1}^{\alpha 2} vab \, .d\,(\omega t)$$

It is seen from fig (c) that the value of vab at ωt = 0 is Vml .sin 30° and its periodicity is 60° or $\pi/3$ rad.

$$V_0 = \frac{3}{\pi} \int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \text{Vml} \sin(\omega t + 30).\, d(\omega t)$$

$$=3.\frac{V_{ml}}{\pi} = \frac{3\sqrt{2}V_l}{\pi} = \frac{3\sqrt{6}V_p}{\pi}$$

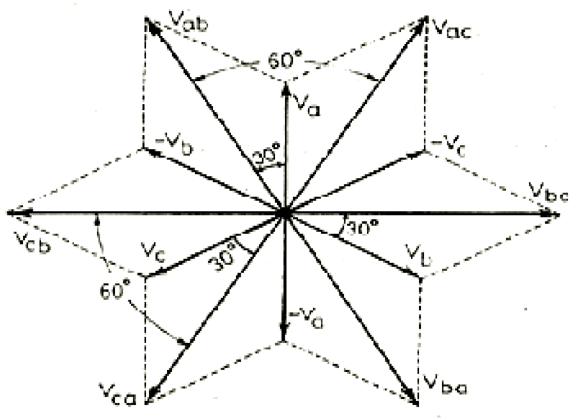


Fig- 9: Secondary voltage phasor diagram

At full load conditions, the input current THD can exceed 100% with no harmonic filter with the 5th and 7th harmonics being the dominant harmonic components. The input current is combination of 5th and 7th harmonic. Harmonic spectrum also shown in fig [8]

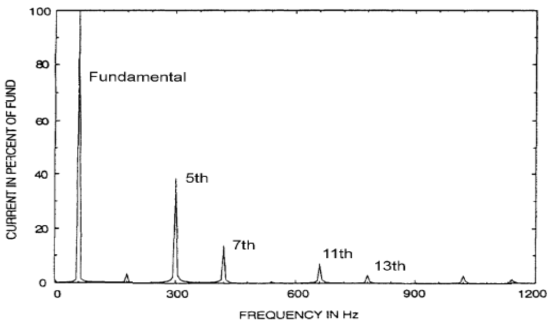


Fig- 10: Harmonic Spectrum for 6 Pulse Rectifiers

Simulations & Results:

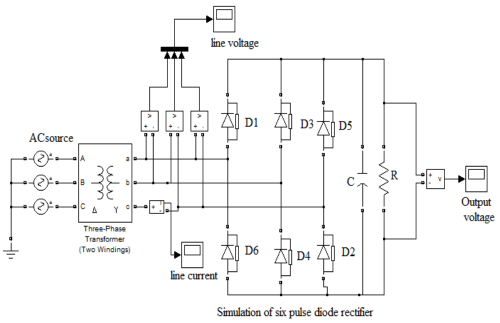
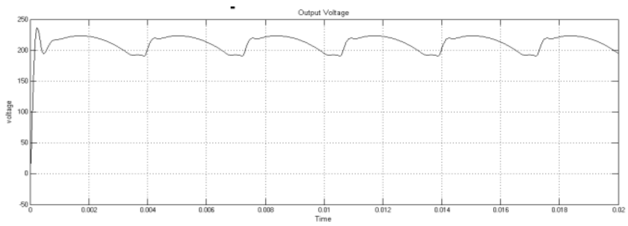


Fig- 11: Simulation of six pulse diode rectifier



Figu- 12: Output Voltage Waveform

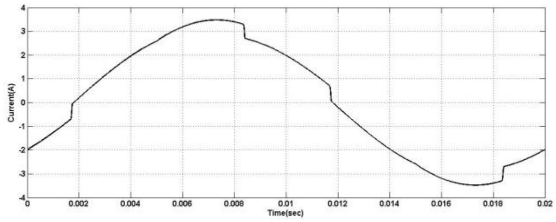


Fig- 13: Input line current waveform

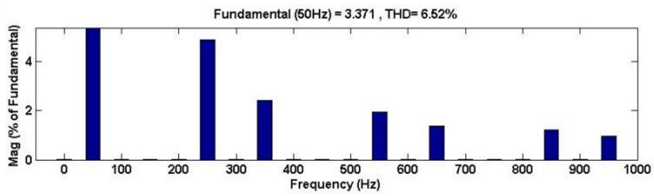


Figure 14 Harmonic Spectrum

3.2 Twelve Pulse Rectifier:

The twelve pulses AC to DC converter are also popularly known as three-phase twelve pulse rectifier. As the number of pulses per cycle is increased, the output DC waveform gets improved. So, with twelve pulses per cycle, the quality of output voltage waveform would definitely be improved with low ripple content.

Figure [15] the circuit diagram for a 3-phase 12-pulse rectifier using a total of twelve diodes. A 3-phase transformer with two secondary and one delta-connected primary feeds the diode rectifier current. One secondary winding is connected in star and the other in delta. Star-connected secondary feeds the upper 3-phase diode bridge rectifier 1, whereas the delta-connected secondary is connected to lower 3-phase diode bridge rectifier 2. Each bridge rectifier uses six diodes as shown. The two bridges are series connected so that the net output, or load, voltage v_o = (output voltage of upper rectifier, v_{01})+ (output voltage of lower rectifier v_{02}).

If V_{a1} , V_{b1} , V_{c1} are phase for the upper star, then upper line voltage V_{ab1} would lead V_{a1} by 30^o as in a three-phase bridge rectifier of the figure. Similarly, line voltages V_{bc1}, V_{ca1} would lead by 30^o their corresponding phase voltages V_{b1} and V_{c1} respectively. In fig [15] are shown all the six line voltages V_{ab1}, V_{ac1} , V_{bc1} , V_{ba1} , V_{ca1} , V_{cb1} for the upper star-connected secondary.

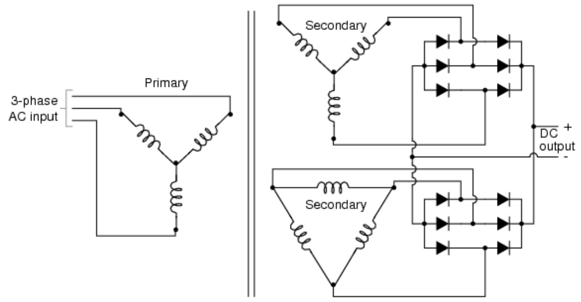


Fig- 15: Diagram for 12 Pulse Diode Rectifier

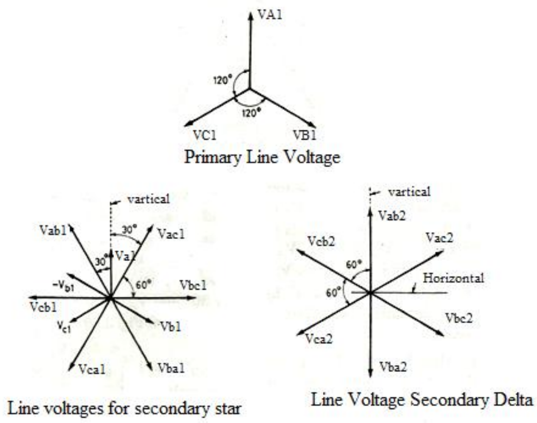


Fig-16: Phasor diagram for Twelve Pulses

Phase voltage V_{a1} of upper star must be in phase with primary line, or phase voltage V_{a1} as per the transformer principle. Likewise, line, or phase, voltage V_{ab2} of the delta-connected secondary must be in phase with V_{a1}. All the secondary line voltages V_{ab2} , V_{ac2} , V_{bc2} , V_{ba2} , V_{ca2} , V_{cb2} for the delta-connected secondary as shown in figure [16]. The line voltages V_{ab1} for upper rectifier and V_{ab2} for lower rectifier are phase-displaced by 30° with Vab1 leading V_{ab2} by 30°. In case input line voltages to upper rectifier 1 and lower rectifier 2 are superimposed ; line voltages V_{ab1} , V_{ab2} , V_{ac1} , V_{ac2} etc. would be obtained ; these line voltages would be phase-displaced from each other by 30°. Six pulse dc output voltage v_{01} obtained from upper rectifier. Lower rectifier 2 also gives six- pulse dc output voltage v_{02}.As V_{ab2} lags V_{ab1} by 30°, peak of v_{ab2} of v_{02} is also shown lagging peak of vab1 of v_{01}.

Since the two rectifiers are series connected, net output, or load voltage $v_o = v_{01} + v_{02}$ is obtained by adding the corresponding ordinates of v_{01} and $v_{02}$are phase-shifted from each other by 30°, therefore, waveform of output voltage v_0 consists of twelve pulses per cycle of supply voltage.

Simulations & results:

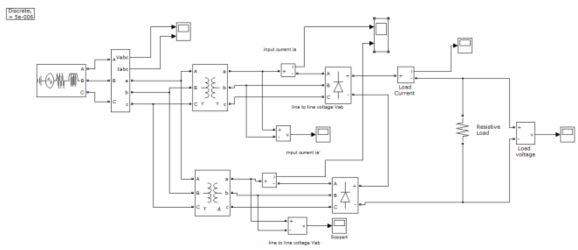


Fig- 17: Simulation of six pulse diode rectifier

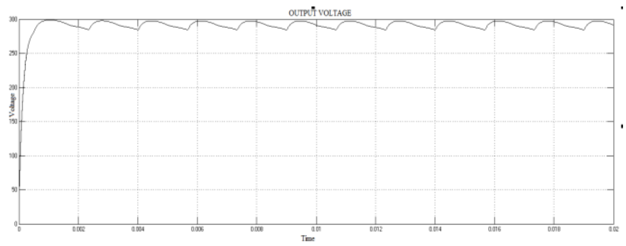


Fig-18: Output Voltage Waveform

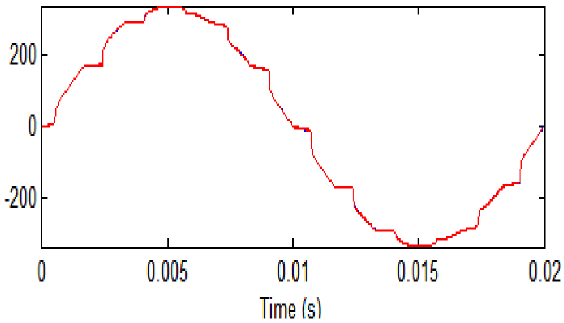


Fig-19: Input line current waveform

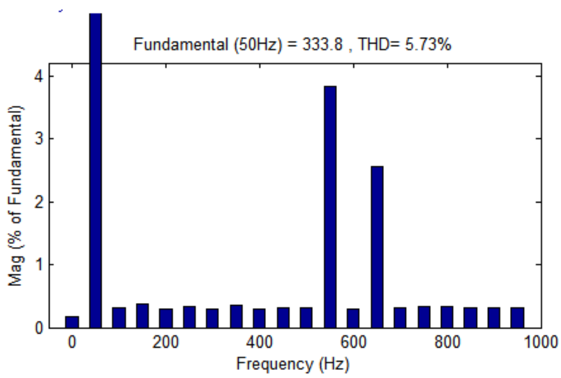


Fig-20: Harmonic Spectrum

3.3 Eighteen Pulse Rectifier

Using the series rectifier connection, it is very easy to construct an eighteen-pulse diode rectifier from a standard six-pulse diode rectifier if the six-pulse drive has its DC bus terminals available or permits access to one side of the DC This transformer is connected in star-star and the other one is connected in delta in order to provide 15^o phase shift. The operation of conventional 18 pulse converter result in the absence 17th and 19th harmonic in input line current.

18-pulse converter is composed of three six pulse bridge rectifier and phase shifting transformer. As six phases supply is needed for feeding three six pulse bridge. But the 15^0 shifting voltage is needed which accomplished by different connection of transformer. Bridge can be connected in an way in series or in parallel as the application But have nearly sinusoidal input current so low THD than 6 pulse converter. The THD of the input current is 4.84%. Simulation shows the series connected bridge with star-delta 18 pulse is generated per AC cycle of input. AC line current is shown in fig below.

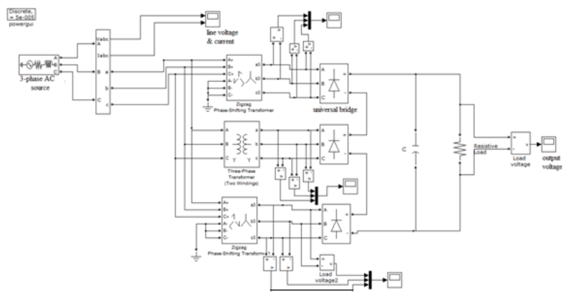


Fig-21: Simulation diagram of 18 pulse diode rectifier

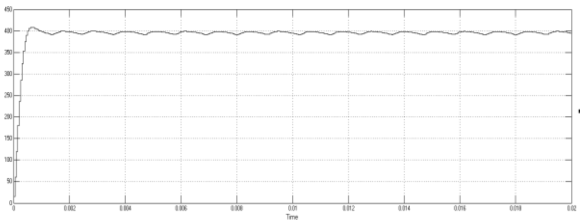


Fig-22: Output voltage waveform

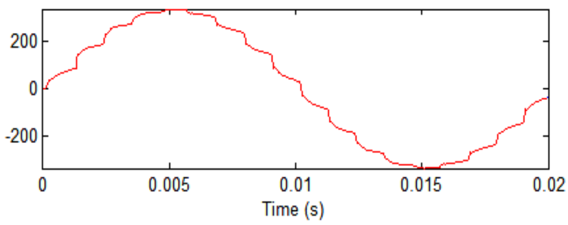


Fig- 23: Input line current waveform

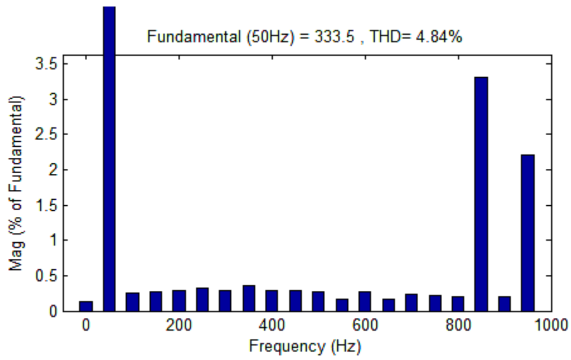


Fig-24: Harmonic Spectrum

3.4 Twenty four pulse rectifier

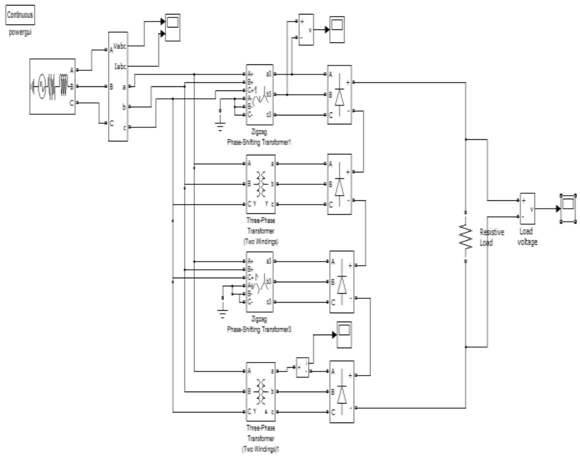


Fig-25: Simulation diagram of 24 pulse diode rectifier

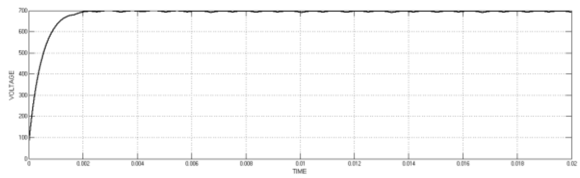


Fig-26: Output voltage waveform

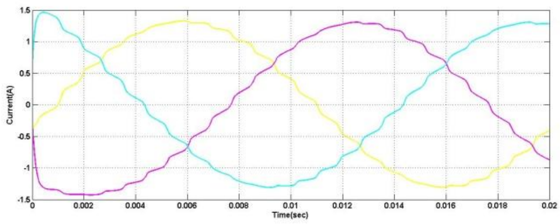


Fig-27: Input current waveform

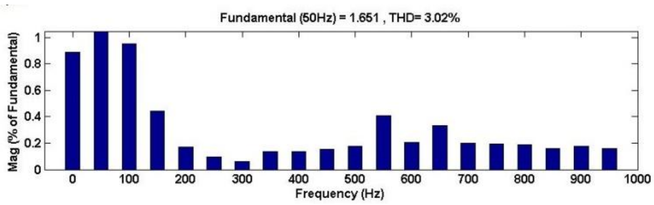


Fig-28: Harmonic Spectrum

3.5 Thirty Six Pulse Rectifier

This system reduces THD in the a source current from IEEE standard of 519 and the THD is less than 5 % and lower ripple in the dc output voltage with the advantage of simple, lower source voltage, THD, size and cost. Harmonic distortion caused by nonlinear loads is becoming a growing problem as nonlinear loads continue to become prevalent in many commercial and industrial applications. This all techniques have been proposed to solve the harmonic current problems.

Thus, finally the realization of the 36-pulse rectifier involves obtaining four 3-phase systems with a defined phase shift between them from a single 3-phase system using interconnection of three-phase and single-phase transformers. For this we are using special transformer called phase-shifting transformer. Before understanding this 36 pulse uncontrolled rectifier we already studied the 6 pulse rectifier and 12, and18 pulse rectifier and there simulations and comparison of each multi pulse rectifier. Below figure shows the basic block diagram of the 36 pulse diode rectifier.

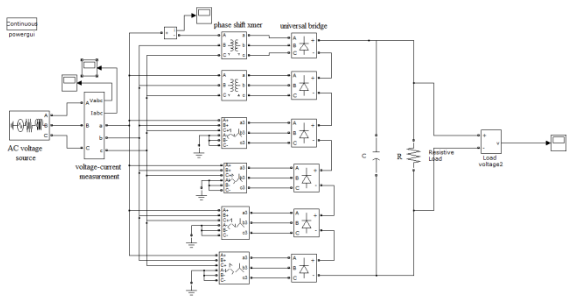


Fig-29: Simulation diagram of 36 pulse diode rectifier

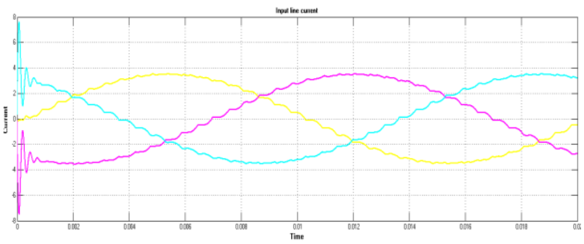


Fig-30: Waveform of input current

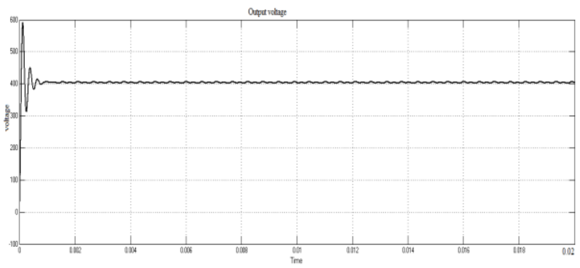


Fig-31: Output voltage waveform

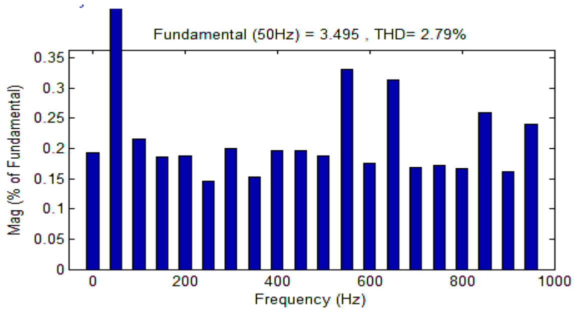


Fig-32: Harmonic Spectrum

Table 3 THD Comparison for Multi pulse Rectifiers

SR No.	No. of pulses	THD for R load
1	6	6.52
2	12	5.73
3	18	4.84
4	24	3.02
5	36	2.79

3. CONCLUSIONS

Multi pulse uncontrolled rectifier can designed using different types of phase shifting transformer with different phase shifting angle like 0°, 30°, 20°, 15° and 10° and because of it the THD of multi pulse rectifier can decrease by increasing the number of pulse.

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