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# Comparative Analysis of Multi-Pulse Controlled Converters using Zigzag Transformers

**Amit Kumar, Saurabh Gupta**
Department of Electrical and Electronics Engineering,
TechnocratsInstitute of Technology and Science Bhopal

**Abstract:-** This paper presents a thyristor-based controlled 18-pulse AC to DC converter zigzag Phase-Shifting double winding transformer (a three-phase transformer with a primary winding connected in an associated zigzag setup and a configurable secondary winding). The 18- pulse AC - DC converter is liked to develop swell variables further, confined primary and secondary windings keep up with separation, and voltage guidelines can be maintained by adjusting the firing angle point of the thyristor, so the proposed work is helpful where smooth, and directed. Separated power is required. This approach eliminates the intricacy required to design complicated autotransformers or isolated multi-winding transformers used with other systems. The paper additionally presents the examination of 12-pulse and 6-pulse AC - DC converters for various boundaries like wave factor, harmonic distortion in input current for unbalanced supply voltage, the efficiency of the converters, and power factor variations of input power supply. All these parameters are compared for no-load light loads and full-load conditions. We further broaden our recreation for estimating the impacts of channels like L, C and LC in the simulation results, showing some beneficial and exciting results.

**Keywords:-** 18-Pulse ac–dc converter, zigzag transformer, three-phase rectifier.

## 1. Introduction

Thyristor-controlled rectifiers have been commonly used in medium and high-power industrial applications (up to 10MW) such as uninterruptible power supplies (UPS), some types of variable speed drives (VSD), electrolysis and metal industries, traction applications, DC arc furnaces, resistive heating, plasma cutting and high voltage DC transmission which requires DCvoltage control Many methods based on the multi-pulse switching have been proposed which are based on autotransformer or multi winding isolation transformer. However, both provide a small transformer size but need a complex structure. Also, the autotransformer lacks the isolation between input and output, and others also can be entirely damaged by accidental overloading of any phase because all primary windings are common.

## 2. Related Work

Some of the literature we studied to develop our concept is discussed below [1,2]. Due to non-linear characteristics, thyristor-controlled rectifiers inject harmonics into the AC mains, which affect the grid and other equipment around the point of common coupling (PCC), and this effect increases when the grid voltage becomes unbalanced [3]. Harmonic values up to the 50thlevel of the voltage and current have been investigated and considered related to several national standards [4]. DC voltage and current can be controlled by adjusting the firing angle of the thyristor. However, the phase control action inherently results in poor displacement power factor and total harmonic distortion (THD) of current.

Furthermore, the line current is typically rich in low-frequency harmonics. In order to meet international standards such as IEEE-519 and IEC- 1000-3-4, passive and active filtering techniques must be employed [2]. Active power factor correction (PFC) circuits, PWM rectifiers, serial and parallel active filters and LC passive filters are used to reduce the harmonic effects in line current and improve the system power factor [5]. However, these methods have some disadvantages. Passive methods are effective for certain load conditions and harmonics (like 5-7, 11-13) and increase the system size and cost. Active methods are limited for high-power applications and cause Radio Frequency Interference (RFI) and Electro Magnetic Interference (EMI). In addition, they increase the rectifier output voltages and the system cost and decrease the efficiency compared to diode/thyristor rectifiers [4- 7].

Furthermore, IGBT rectifiers, up to a few hundred kW power levels, draw capacitive current from the line at low load levels and cause capacitive penalties. These drawbacks are significant in high-power applications [8]. Instead of using special filters to reduce the line current harmonics in rectifiers, it is reasonable to build a multi-pulse rectifier which keeps harmonics at acceptable levels according to international standards and never draws capacitive currents [2]. Multi-pulse rectifiers can be obtained by producing two or more three-phase voltages using phase shifting and then connecting the rectifiers as serial or parallel at the output. Multi-pulse rectifiers, designed with phase-shifting autotransformers without isolation from the line, are frequently used in varying load applications[9]. If the pulse number of a rectifier is increased, harmonics in the grid currents are decreased [4, 10]. The relation between the pulse number and line current harmonics is represented in equation 1.

$$h = p^{*}n \mp 1, n = 1, 2, 3, \ldots \qquad (1)$$

where P is the pulse number, and h is the number of harmonics.

The 18-pulse diode rectifiers are cost-effective multi-pulse methods and can meet IEEE-519 standards without requiring extra filter circuits [11]. Formerly, multi-pulse controlled rectifiers were not used because of their complexity and control difficulties. However, along with the increasing number and power levels of the rectifiers, the significance of the power quality and multi-pulse rectifiers is also increased. 12 pulse-controlled rectifiers have been studied [12]. But the line current harmonics and the power factor of the 12 pulse rectifier could not reach the excepted levels. In this paper, an 18-pulse controlled rectifier with low THD and high power factor is introduced and tested for resistive and R-L load supply applications for different output DC voltage levels. 20° phase difference is obtained using a zigzag transformer with a 10kVA rating. 18 pulse rectifier's line current harmonics and the power factor are documented. 6 and12 pulse-controlled rectifier results are also given. Simulation and experimental results of the proposed 18-pulse controlled rectifier show that the line current harmonics are low and the power factor is high even in higher values of firing angle. The ripple's effective (RMS) value reaches about 0.5%, so high-quality DC voltage is obtained using 18-pulse rectification.

## 3. Proposed Work

Because we have to compare different configurations, figure 1 shows the basic model of six uncontrolled pulse rectifier, which is also used as the base unit for 12 and 18-pulse systems. The Simulink model shows the zigzag transformer, although it is not required for the six-pulse system. However, because for a higher pulse, the proposed model consists of zigzag transformers with different phase shifts, we selected this with zero phase shift instead of the standard transformer to achieve a fair comparison because the change in the type of transformer may cause a slight change in its parameters. The rectifier is designed for a 10KVA rating at 230V 50Hz AC the transformer used is also rated for the same with a turn ratio of one to measure the different parameters of the rectifier, like THD and Ripple ratio. Some other components are connected to the circuit. In the circuit for analysis, an R- L load is connected at the output of the rectifier, which can be varied for measuring the condition of the rectifier at different load conditions. The base circuit also uses passive L-C filters, as shown in the figure. Although we are showing one model for simplicity, all configurations of filters are considered for analysis.

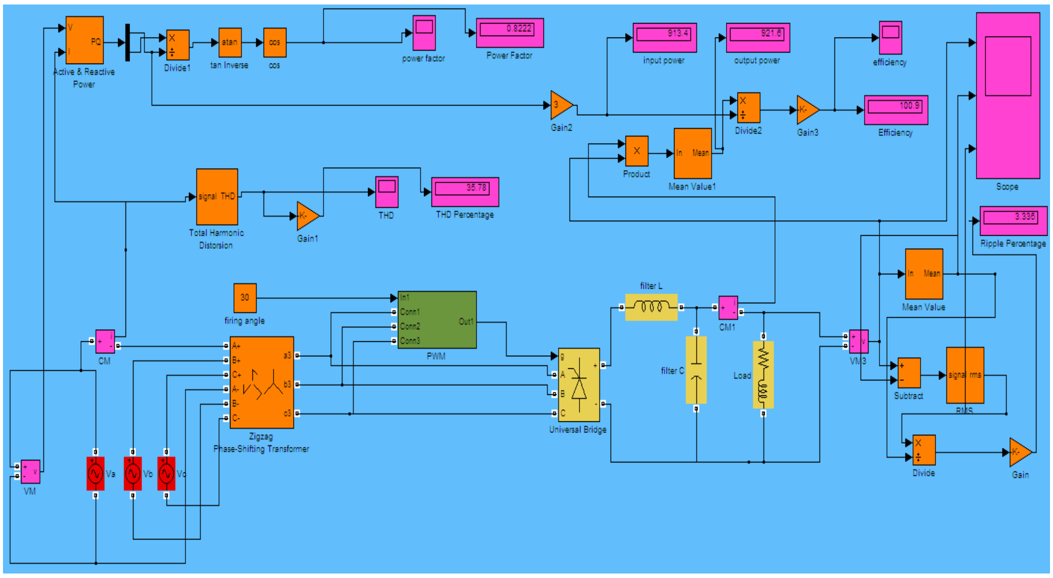


Figure 1 Simulink Model of the 6-pulse converter.

The ratings of the components selected for the simulation are as follows: (1) Voltage source: The 230V, AC, and 50Hz are all three sources that are shifted by 120 degrees in a relative phase. (2) Transformer: Zigzag is used for 6-pulse zero degrees phase shift, 12-pulses 30-degree phase shift and 18-pulse 20-degree phase shift. The transformer is rated 10KVA at 230V 50Hz the turn ratio is selected as one.

(3) Universal Bridge: three arms, six thyristor standard bridge with snubber resistance of 100K ohms and capacitor of 0.1 microfarads. (4) Load: the load is selected according to equation 2 for the complete load condition.

$$10^3*K*P = \frac{(K*1.35*230)^2}{R} \qquad (2)$$

Where K = 1, 2 or 3 according to 6-pulse, 12-pulse or 18-pulse.

P represents the loading factor equal to one for a full load. From expression (2), the value of the R variable can be easily found for different operating conditions. The value of L is selected by considering the ratio of stored power to dissipated power. Where stored is represented $(1/2)*L*I^2$ and dissipated power as $I^2R$. For the 12 and 18 pulse models, some measuring blocks are eliminated to fit Figures 1 and 2. The simulation results of all three converters for different conditions are shown in tables 1 and 2. Table 1. Results for Balanced input firing angle 30 degrees.

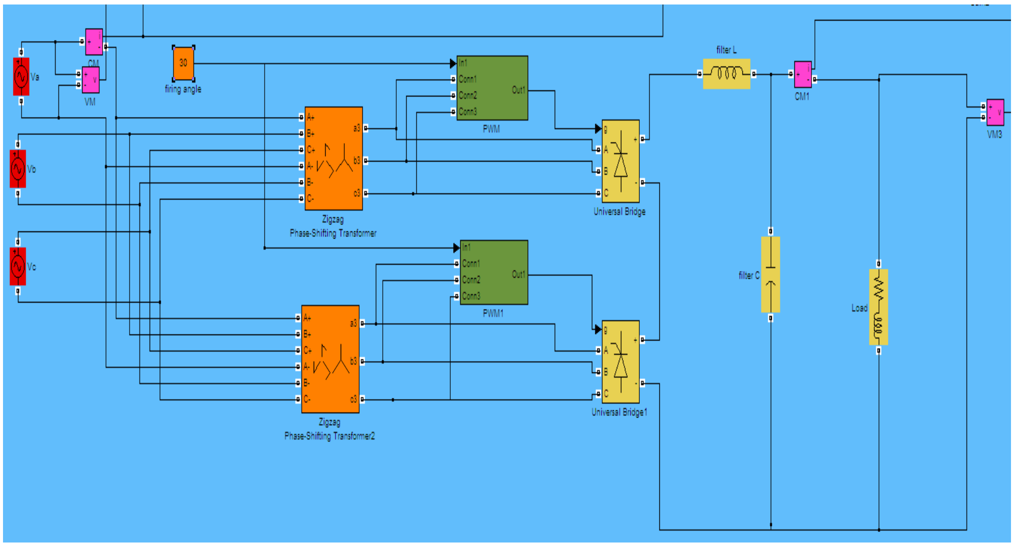


Figure 2 Simulink model for 12 pulse converter

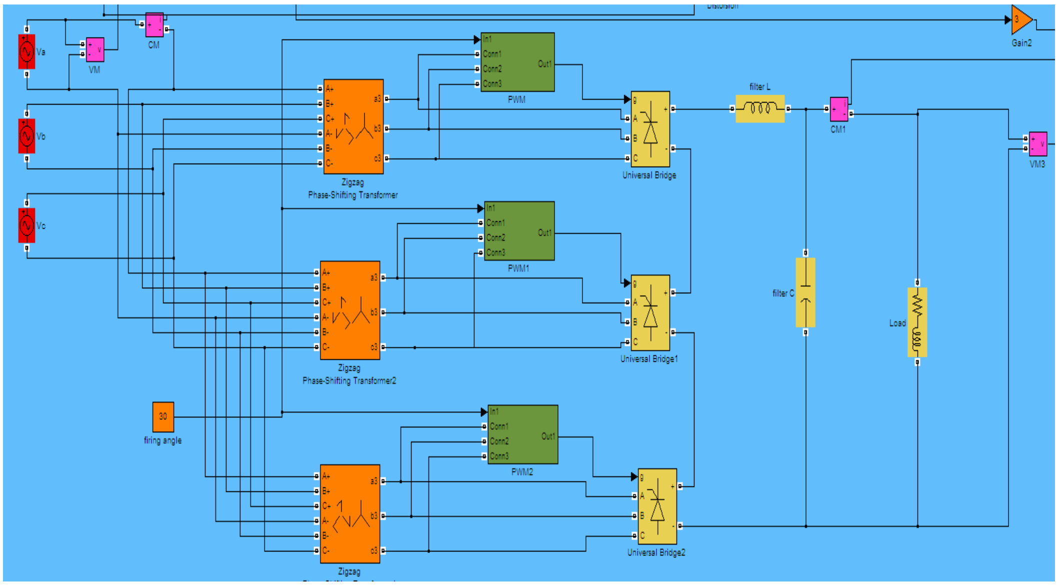


Figure 3 Simulink model for 18 pulse converter

Table 1 (A). for full load (Resistive only)

| Type | THD(Percentage) | | | Ripple(Percentage) | | | Efficiency(Percentage) | | | Power Factor | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | C | LC | L | C | LC | L | C | LC | L | C | LC |
| 6-pulse | 23.07 | 25.79 | 21.43 | 2.331 | 10.03 | 1.554 | 93.18 | 98.70 | 96.37 | 0.6995 | 0.6848 | 0.6441 |
| 12-pulse | 11.35 | 14.38 | 11.58 | 1.872 | 4.355 | 1.617 | 98.01 | 98.12 | 98.22 | 0.6858 | 0.6809 | 0.6795 |
| 18-pulse | 8.711 | 11.12 | 9.297 | 2.486 | 4.011 | 1.201 | 97.92 | 94.52 | 97.97 | 0.7635 | 0.6102 | 0.7367 |

Table 1 (B). for light load 20% (Resistive only)

| Type | THD(Percentage) | | | Ripple(Percentage) | | | Efficiency(Percentage) | | | Power Factor | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | C | LC | L | C | LC | L | C | LC | L | C | LC |
| 6-pulse | 28.24 | 135.9 | 24.48 | 3.303 | 55.98 | 3.108 | 98.22 | 95.48 | 98.47 | 0.7349 | 0.8678 | 0.7370 |
| 12-pulse | 14.52 | 80.18 | 15.23 | 3.021 | 19.14 | 0.635 | 99.15 | 98.57 | 99.01 | 0.8100 | 0.9866 | 0.7928 |
| 18-pulse | 10.78 | 80.54 | 9.352 | 2.747 | 10.56 | 0.599 | 97.66 | 90.22 | 98.21 | 0.8212 | 0.9528 | 0.7905 |

Table 1 (C). for R-L load (Stored energy 20%)

| Type | THD(Percentage) | | | Ripple(Percentage) | | | Efficiency(Percentage) | | | Power Factor | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | C | LC | L | C | LC | L | C | LC | L | C | LC |
| 6-pulse | 22.48 | 32.08 | 24.77 | 17.05 | 30.66 | 6.182 | 98.05 | 96.68 | 96.38 | 0.6878 | 0.7169 | 0.7044 |
| 12-pulse | 12.44 | 26.17 | 11.94 | 7.212 | 32.10 | 2.149 | 98.22 | 71.94 | 98.31 | 0.6826 | 0.9811 | 0.7031 |
| 18-pulse | 8.589 | 23.83 | 6.875 | 4.892 | 22.19 | 1.497 | 99.97 | 64.76 | 93.47 | 0.7548 | 0.9981 | 0.7680 |

Table 2. Results for Unbalanced input (One phase Variation by 10%) firing angle 30 degrees.

Table 2 (A). for full load (Resistive only)

| Type | THD(Percentage) | | | Ripple(Percentage) | | | Efficiency(Percentage) | | | Power Factor | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | C | LC | L | C | LC | L | C | LC | L | C | LC |
| 6-pulse | 23.17 | 27.85 | 20.94 | 1.326 | 15.87 | 1.281 | 98.88 | 98.21 | 99.01 | 0.6699 | 0.6672 | 0.6629 |
| 12-pulse | 12.49 | 23.74 | 10.54 | 1.777 | 12.74 | 1.784 | 97.24 | 97.01 | 96.23 | 0.7324 | 0.6717 | 0.7804 |
| 18-pulse | 9.832 | 36.71 | 10.15 | 4.998 | 15.71 | 3.793 | 97.67 | 90.22 | 97.92 | 0.7298 | 0.5128 | 0.7697 |

Table 2 (B). for light load 20% (Resistive only)

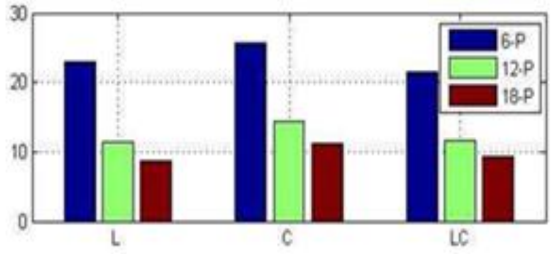
| Type | THD(Percentage) | | | Ripple(Percentage) | | | Efficiency(Percentage) | | | Power Factor | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | C | LC | L | C | LC | L | C | LC | L | C | LC |
| 6-pulse | 30.98 | 140.0 | 31.84 | 3.525 | 45.48 | 4.757 | 98.22 | 99.80 | 98.76 | 0.7663 | 0.8442 | 0.7780 |
| 12-pulse | 18.17 | 79.16 | 16.32 | 7.676 | 18.17 | 1.712 | 98.01 | 90.72 | 98.77 | 0.7822 | 0.3991 | 0.8361 |
| 18-pulse | 10.61 | 70.9 | 15.96 | 3.456 | 10.05 | 1.285 | 97.21 | 90.47 | 98.11 | 0.8071 | 0.9963 | 0.8432 |

Table 2 (C). for R-L load (Stored energy 20%)

| Type | THD(Percentage) | | | Ripple(Percentage) | | | Efficiency(Percentage) | | | Power Factor | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | C | LC | L | C | LC | L | C | LC | L | C | LC |
| 6-pulse | 24.69 | 33.89 | 24.20 | 14.52 | 41.09 | 13.06 | 98.87 | 98.98 | 98.71 | 0.6582 | 0.7133 | 0.6769 |
| 12-pulse | 10.53 | 198.1 | 11.62 | 7.827 | 80.05 | 2.561 | 98.26 | 95.26 | 98.21 | 0.7412 | 0.8921 | 0.7197 |
| 18-pulse | 10.07 | 66.63 | 8.250 | 5.897 | 46.66 | 8.155 | 98.91 | 95.87 | 98.45 | 0.7338 | 0.9672 | 0.7705 |

## 4. Results and Discussion

The proposed 12- and 18-pulse ac–dc converters have been modelled and designed for R-Load in MATLAB environment along with Simulink and Power System toolboxes. The overall performance of the converter, with different loads fed by a 6-pulse, 12-pulse and 18-pulse thyristor bridge rectifier with a firing angle selected to 30 degrees, are listed in the tables above. The comparative bar graphs generated for easy visualization are shown in Figures 4 and 5. The analysis shows that 18 pulse converter provides the best performance for every condition. It also shows (the peaks of 'C' bars) that abruptly selected values of elements may not improve the performance. Hence, filter calculations are required according to the load type.



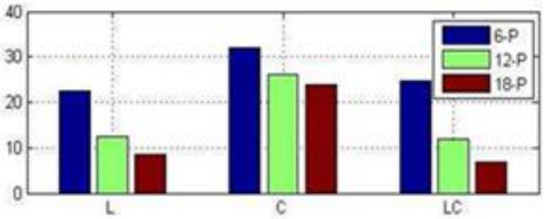


Figure 4 THD (in %) comparisons of all converters for R (Top) and R-L (Bottom) loads.

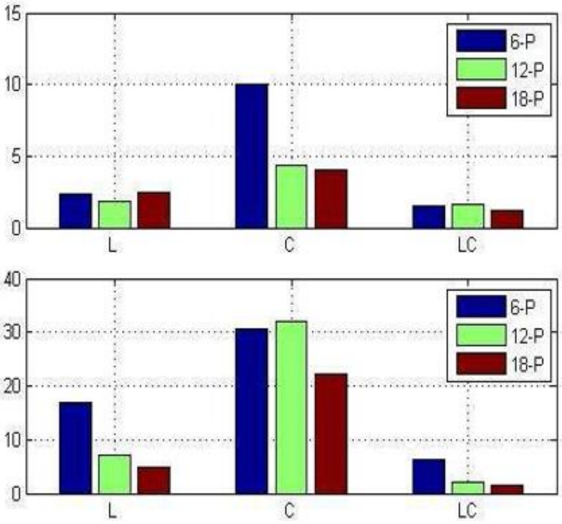


Figure 5 Ripple (in %) comparisons of all converters for R (Top) and R-L (Bottom) loads.

## 5. Conclusion

The proposed ac-dc converter has shown the flexibility to vary the voltage, making it suitable for controlled voltage applications. The performance of the proposed eighteen-pulse ac-dc converter has been found satisfactory under varying load conditions. The proposed ac-dc converter can provide close to unity power factor in the wide operating range of the drive. The proposed converter has resulted in a reduction in the rating of the magnetics leading to the saving in the overall cost of the drive. The obtained experimental results on the proposed converter have demonstrated the capability of this converter to improve the power quality indices at ac mains in terms of THD of supply current, efficiency, power factor and ripple factor.

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