

## Harmonic Analysis of 6-Pulse and 12-Pulse Converter Models

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**Abstract:** This paper discusses the impact of using 6-pulse and 12-pulse rectifier circuit commonly found in HVDC systems. The 12-pulse rectifier circuit is known to be more expensive, but produces the reduced input current harmonics and output voltage ripples. The Multi-pulse configuration consists of several six-pulse converter units in either series or parallel on the DC side. These units are phase-shifted with respect to each other by the transformer connection. This paper presents the modeling and simulation of both 6-pulse and 12-pulse rectifier topologies to compare their input current harmonics, output voltage ripples and also total Harmonic Distortion (THD) as well. The input current waveform, voltage waveform and THD have been observed. The rectifiers are modeled and simulated using MATLAB software to compare their harmonic levels.

### I. Introduction

The transmission and distribution of electrical energy Started with direct current (DC) in late 19<sup>th</sup> century, but it was inefficient due to the power loss in conductors. Alternating current (AC) offered much better efficiency, since it could easily be transformed to higher voltages, with far less loss of power. AC technology was soon accepted as the only feasible technology for generation, transmission and distribution of electrical energy [3].

Diode rectifier used passive component and switching devices for reduce harmonic problem, but they are create more complicated system include in high power grid application. The 6-pulse rectifier is involving most AC drive because of its low cost and simplest structure. The input current THD can exceed 100% with no harmonics filter with 5th, 7th and 11th harmonics at full load condition. Harmonics filter with 5th, 7<sup>th</sup> and 11th harmonics being dominant harmonics component. A 12-pulse rectifier involves two sets of 6-pulse rectifier is very popular for different types high power grid application. The multi-phase transformer can be an autotransformer or an isolated transformer with some phase displacement to provide two three-phase voltage sources that cancel the 5th and 7th harmonics. 12-pulse rectifier with a wye-wye, wye--delta isolation transformer and the resulting input current waveform where 11th and 13th harmonics are the dominant harmonic components [5].

As technology grows every day, the study of power systems has shifted its direction to power electronics to produce the most efficient energy conversion. Power electronics plays a vital role in processing and controlling the flow of electric energy by supplying voltages and currents in a form that is suited for user loads. The goals of using power electronics are to obtain the benefit of lower cost, small power loss and high efficiency. Because of high energy efficiency, the removal of heat generated due to dissipated energy is lower. Other advantages of power electronics are reduction in size, weight, and overall cost [4].

### II. 6--Pulse And 12-Pulse Rectifier Models

The basic configuration for HVDC uses a three phase bridge rectifier or six pulse bridges, containing six electronic switches, each connecting to one of the three phases power supply. A complete switching element is usually referred to as a valve, irrespective of its construction. The simulated diagram of six Pulse Bridge is shown in figure.1. Normally, two diodes in the bridge are conducting at any time, one on the top row (D1, D3 and D5) and another from bottom row (D2, D4 and D6). The two conducting valves connecting to two of three AC phase voltages, in series to the DC terminals. Thus the DC output voltage at any given instant is given by the series combination of two AC phase voltages. For example, if valves D1 and D2 are conducting, then the DC output voltage is given by the voltage of phase 1 minus the voltage of phase 3.

In fact, with a line commutated converter, the firing angle represents the only way of controlling the converter output voltage. Firing angle control is used to regulate the DC voltages of both ends of the HVDC system continuously in order to obtain the desired level of power transfer.

For high power applications such as high voltage DC transmission and DC motor drives, a 12 pulse output is generally required to reduce the output ripples and to increase the ripple frequencies. A three phase bridge gives a six pulse output voltages. An enhancement of the six pulse bridge arrangement uses 12 valves in a twelve pulse bridge. A twelve pulse bridge is effectively two six pulse bridges connected in series on the DC side and arranged with a phase displacement between their respective AC supplies so that some of the harmonics voltages and currents are get cancelled.

The phase displacement between the two AC supplies is usually  $30^\circ$  and is realized by using converter transformer with two different secondary windings. Usually one of the valve winding is star (wye) connected and the other is delta connected.

MATLAB software, particularly Simulink, MATLAB's graphical interface is a Environment for designing and modeling systems, was used to model various aspects of the proposed power generation and transmission system. MATLAB version 2013, release 07.02.2013, equipped with the SimPowerSystems block set, was the software used.

### 3-Phase diode rectifier using 6-diodes

The MATLAB Sim Power Systems software is a subsystem contains numerous demonstration models, including a model of a 3-phase diode rectifier. This model was the inspiration for our simplified models of 3-phase 6-pulse and 12-pulse converters.

Figure1 shows 6-pulse diode bridge rectifier. The three single-phase AC voltage sources, each 120 degrees out of phase with the other, each being rectified through a diode, RL load was used.

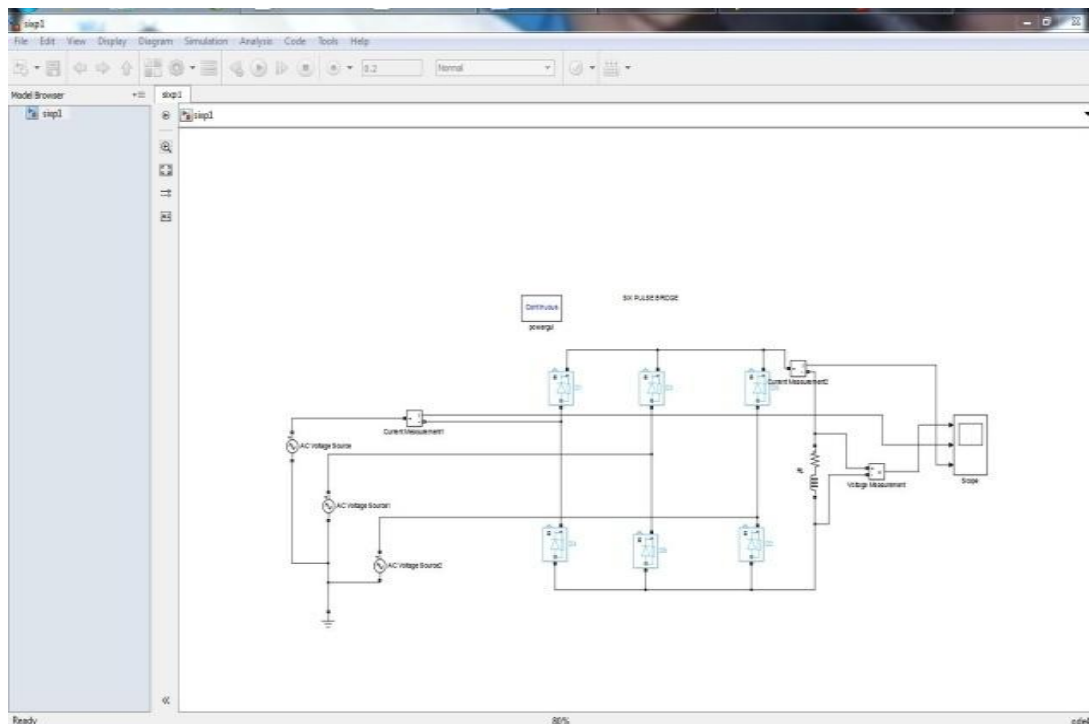


Figure: 1:3-phase diode rectifier using 6-diodes

### 3-Phase diode rectifier using 12-diodes

The MATLAB 3-phase diode rectifier demonstration model, described above, features three single-phase AC voltage sources, each 120 degrees out of phase with the other, each being rectified through a diode and RL load was used.

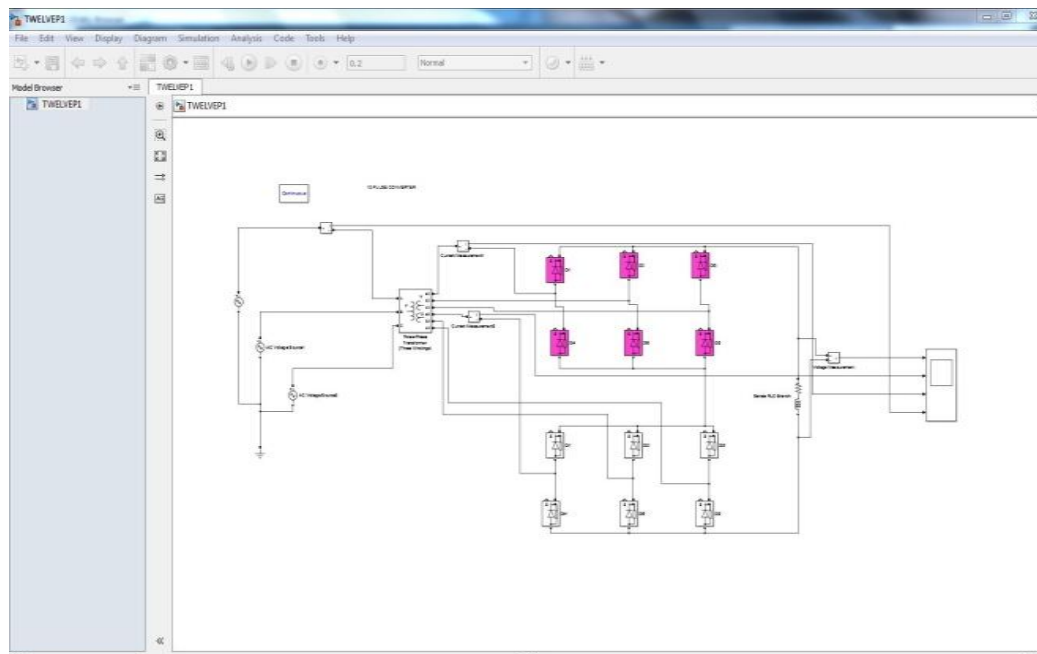


Figure: 2: 3-Phase diode rectifier using 12 diodes.

### 12-pulse converter rectifier, using 12-thyristors

Diodes cannot be used in HVDC converters because the timing of current flow must be precisely controlled, and diodes do not allow this sort of control. 3-Phase diode models using 6-diodes and 12-diodes rectifier models and also 12-pulse rectifier using thyristors model were simulated. Stability is the major problem in diode models, Hence output voltage can be varied in 12-pulse converter using thyristors.

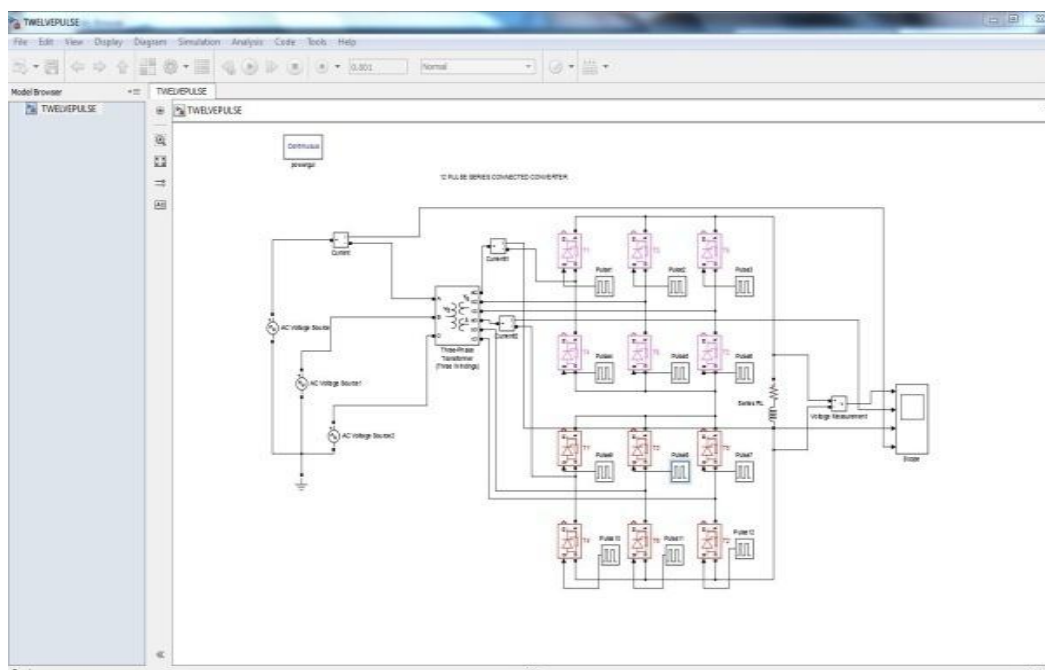


Figure: 3: 12 pulse converter using 12-thyristors.

### III. Simulated Results

Both 6-pulse and 12-pulse rectifier models were simulated. With increasing pulses in the converter, the input side the Total Harmonic Distortion (THD) is reduces and efficiency of the system is increased. For RL type load with  $R= 10 \text{ ohm}$ , and  $L=650\mu\text{H}$ . The results obtained are as follows:

Results obtained for six pulse converter showing output voltage ( $V_d$ ), input current (I), and output current ( $I_d$ ) in figure 4.

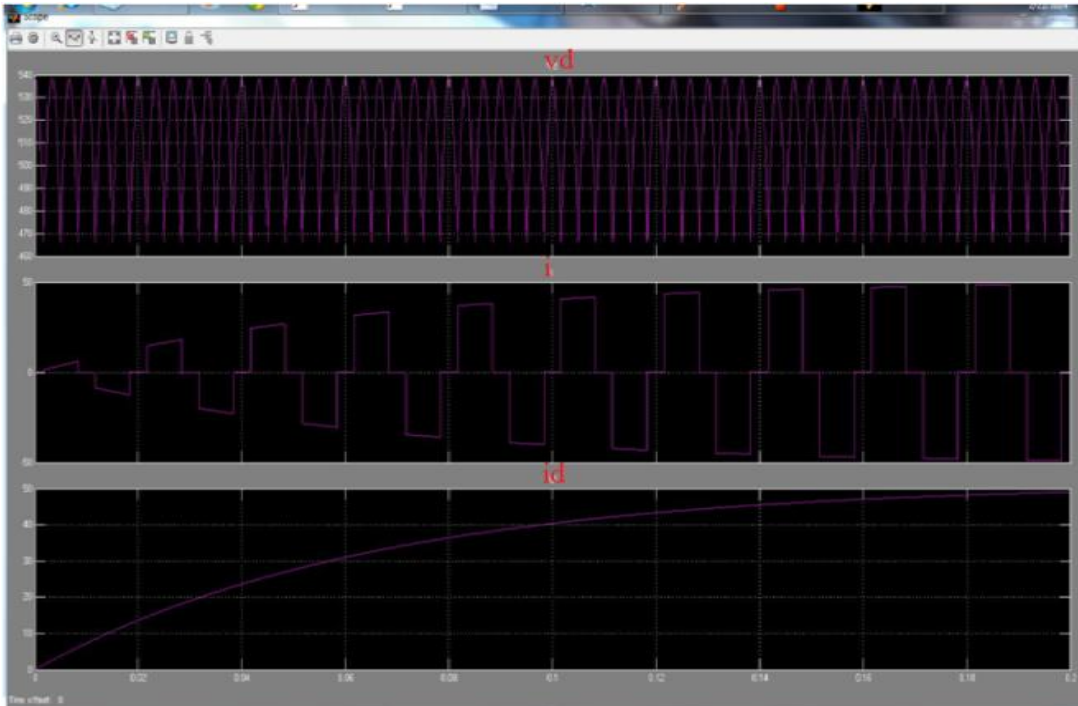


Figure: 4: waveforms of 3-phase diode rectifier using 6-diodes

Results obtained for twelve (12) pulse converter using diodes. Showing output voltage ( $V_d$ ), secondary currents ( $i_1$ ) and ( $i_2$ ), and input current (I) in figure 5.



Figure: 5: waveforms of twelve pulse converter using diodes.

Results obtained for twelve (12) pulse converter using thyristors. Showing output voltage ( $V_d$ ), secondary currents ( $i_1$ ) and ( $i_2$ ) and input current (I) in Figure 6.

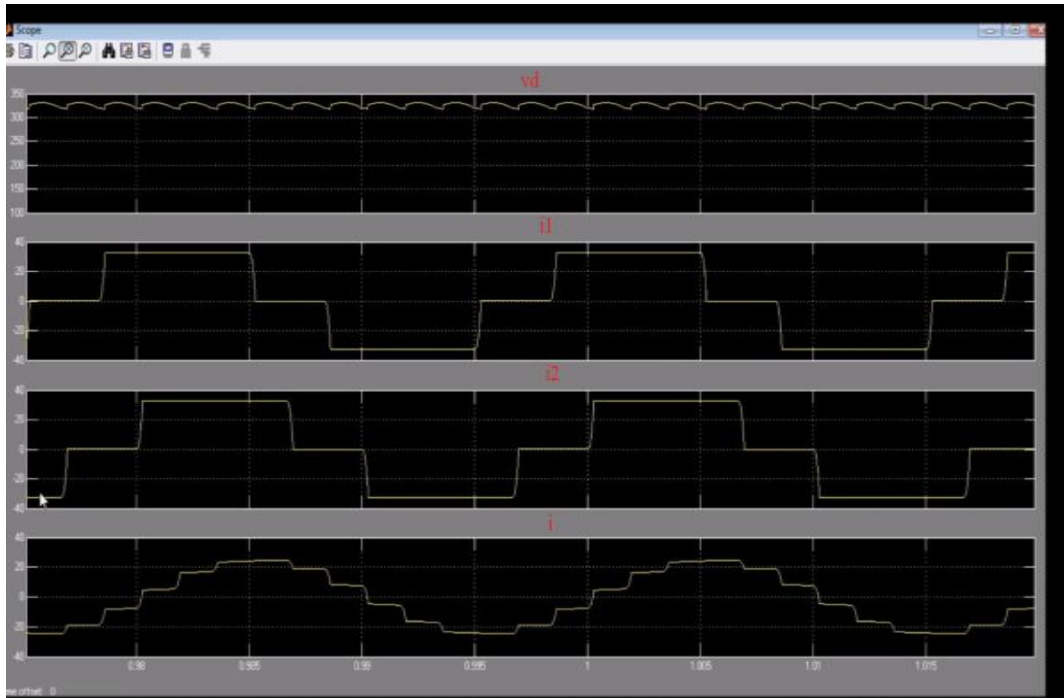


Figure: 6: waveforms of twelve pulse converter using thyristors.

Fast Fourier Transform (FFT) analysis was carried out on both 6-pulse and 12-pulse converters. The analysis shows 11<sup>th</sup> and 13<sup>th</sup> harmonics in 12 pulse converter with 12% of THD.

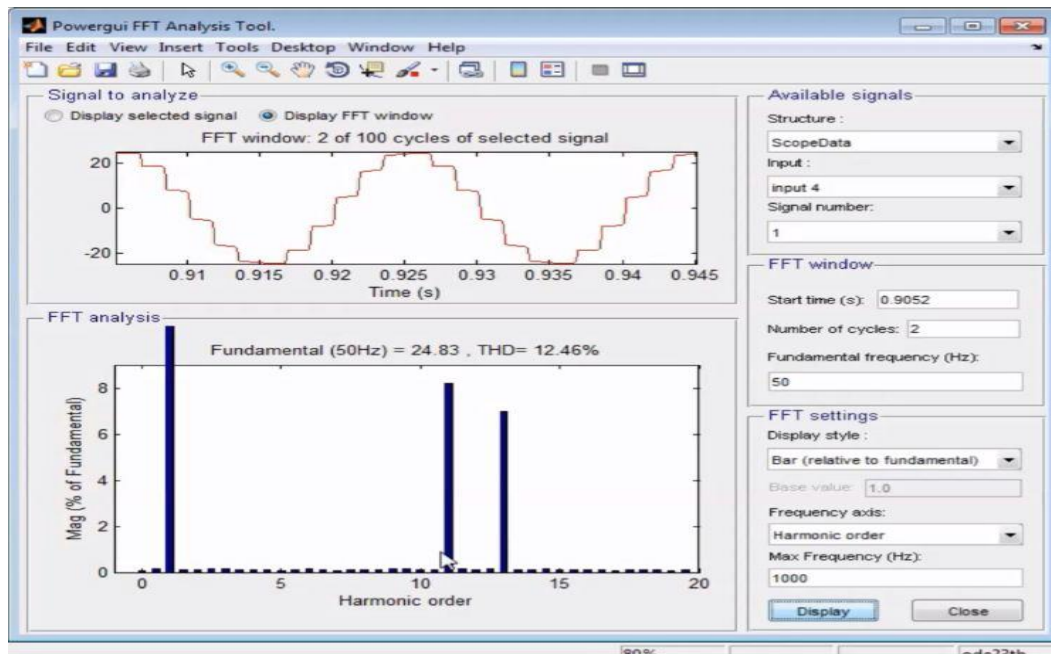


Figure: 7: FFT analysis.

With increasing the pulses in the converter, the input side the Total Harmonic Distortion (THD) has reduces and efficiency of the system is increased. For RL type load with  $R= 10$  ohm,  $L = 650\mu\text{H}$  and the results obtained are as follows:

THD in 6 pulse converter = 36.95 %

THD in 12 pulse converter = 12.48 %

It is observed that the total harmonic distortion (THD) decreases as the number of converter pulses increases and it is within limits as per IEEE standards.

#### **IV. Conclusion**

In the 12-Pulse converter configurations, the output voltage ripple as well as the input phase current harmonic content was much lower as compared to the 6-Pulse converter configurations. As the number of pulses increases, the quality of DC so obtained becomes better as well as the harmonic content in the AC input current is further reduced. Other multi-pulse converter configurations with pulse numbers much higher than 12 and with different configurations, like 18-Pulse, 24- Pulse, 36-Pulse, 48-Pulse configurations, which give much better performance than the 12-Pulse converter. But due to increased circuit complexity and higher number of components involved, their analysis becomes tedious and complex.

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