

Power Quality Improvement by Using Multipulse AC-DC Converters for Varying Loads

B.Suresh Kumar

Asst.Professor,EEE dept,CBIT-Hyderabad

ABSTRACT : *Power electronic devices are non-linear loads that create harmonic distortion and can be susceptible to voltage dips if not adequately protected. The most common economically damaging power quality problem encountered involves the use of variable-speed drives. Variable-speed motor drives or inverters are highly susceptible to voltage dip disturbances and cause particular problems in industrial processes where loss of mechanical synchronism is an issue.*

Three-Phase Ac-Dc conversion of electric power is widely employed in adjustable-speeds drive (ASDs), uninterruptible power supplies (UPSs), HVDC systems, and utility interfaces with non conventional energy sources such as solar photovoltaic systems (PVs), etc., battery energy storage systems (BESSs), in process technology such as electroplating, welding units, etc., battery charging for electric vehicles, and power supplies for telecommunication systems. Traditionally, ac-dc converters, which are also known as rectifiers, are developed using diodes and thyristors to provide uncontrolled and controlled unidirectional and bidirectional dc power. They have the problems of poor power quality in terms of injected current harmonics, resultant voltage distortion and poor power factor at input ac mains and slowly varying rippled dc output at load end, low efficiency, and large size of ac and dc filters

It is well known that undesirable harmonic line currents may be generated during a transformer-rectifier combination. The rectification of AC power to DC power itself may in general produce undesirable current harmonics. These non-linear loads cause severe current harmonics that may not be tolerated by either a shutdown of the device or unacceptable powering of the devices.

The great majority of power electronic equipment operates from an ac source but with an intermediate dc link. Thus, a significant opportunity exists to facilitate power electronics applications by using ac to dc rectifiers that produce low harmonic current in the ac source. Multi-pulse converters in general and non-isolated multi-pulse converters in particular can be applied to achieve clean power which is of major interest in higher power ratings. In general, by increasing the number of pulses in multi-pulse converters THD (total harmonic distortion) can be reduced and other associated performance parameters can be enhanced. This project work is an endeavor towards analyzing the different multi-pulse converters in solving the harmonic problem in a three-phase converter system. The effect of increasing the number of pulses on the performance of AC to DC converters is analyzed.

Introduction : Objective Of Present Study:

This project work is an endeavor towards analyzing the different multi-pulse AC to DC converters in solving the harmonic problem in a three-phase converter system. The

effect of increasing the number of pulses on the performance of AC to DC converters is analyzed. For performance comparison the major factor considered is the total harmonic distortion (THD). The effect of load variations on multi-pulse AC to DC converters has been investigated.

I. About HVDC transmission

The history of electric power transmission reveals that transmission was originally developed with DC. However, DC power at low voltage could not be transmitted over long distances, thus it led to the development of alternating current (AC) electrical systems. Also the availability of transformers and improvement in ac machines led to the greater usage of ac transmission.

Why HVDC?

There are many different reasons as to why HVDC is to chosen instead of ac transmission. A few of them are listed below. Cost effective HVDC transmission requires only two conductors compared to the three wire ac transmission system. One-third less wire is used, thus readily reducing the cost of the conductors. This corresponds to reduced tower and insulation cost, thereby resulting in cheaper construction. However, the ac converters stations involve high cost for installation; thus the earlier advantage is offset by the increase in cost. If the transmission distance is long, a break-even distance is reached above which total cost of HVDC transmission is less than the ac. Asynchronous tie HVDC transmission has the ability to connect ac systems of different frequencies. Thus it can be used for intercontinental asynchronous ties.

1.1 HVDC CONSTRAINTS:

Even though HVDC has many advantages, the whole power system cannot be made DC, because of the fact that generation and distribution of power is ac. So HVDC technology is restricted to transmission.

1.2 BASIC HVDC SYSTEM CONFIGURATIONS:

There are many different configurations of HVDC based on the cost and operational requirements. Five basic configurations are shown in Fig. 1-1. The back-to back interconnection has two converters on the same site and there is no transmission line. This type of connection is generally designed for low ratings and is more economical than the long distance transmission. The converters at both the ends are identical and can be operated either in rectification or inversion mode based on the control. The monopolar link has only one conductor and the return path is through the earth

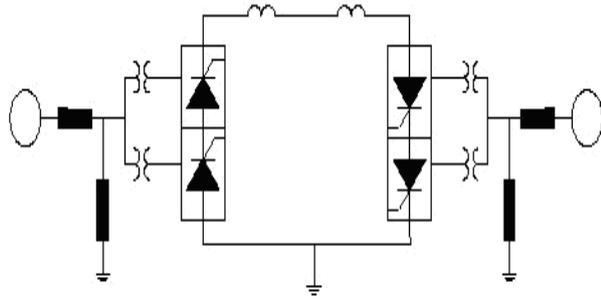


Fig. 1.1. Back-to-back interconnection

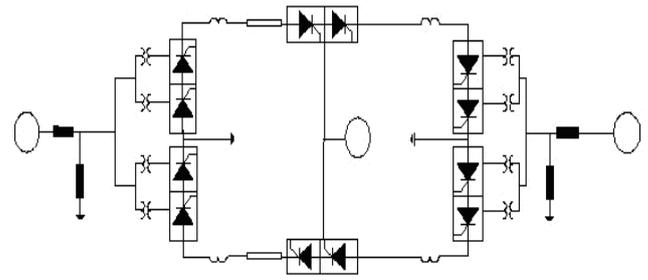


Fig. 1.5. Series connection

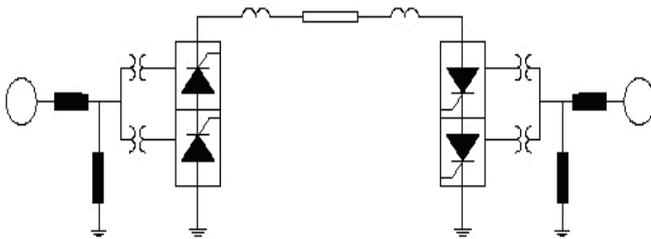


Fig. 1.2. Monopolar link

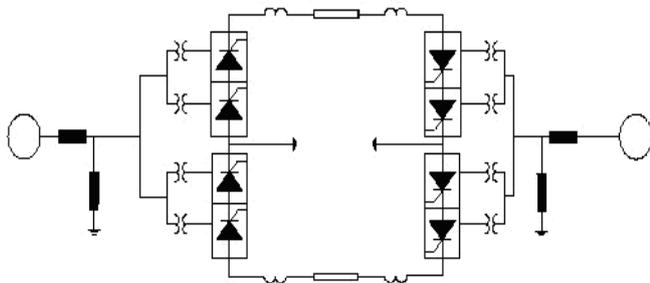


Fig. 1.3. Bipolar link

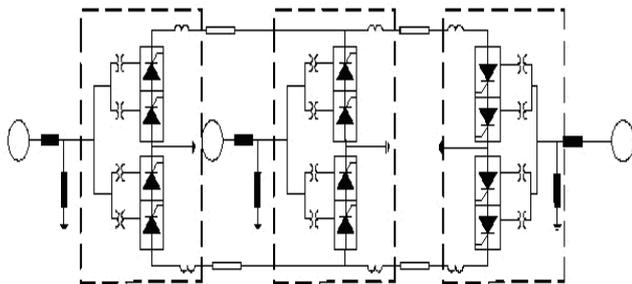


Fig. 1.4. Parallel 3-terminal

1.3 COMPONENTS OF HVDC TRANSMISSION SYSTEM:

1.3.1 The converter station:

The converter stations at each end are identical and can be operated either as an inverter or rectifier based on the control.

This is accomplished in two ways:

- 1) With phase isolated bus bars where the bus conductors are housed within insulated bus ducts with oil or SF6 as the insulating medium,
- 2) With wall bushings and these require care to avoid external or internal breakdown [1].

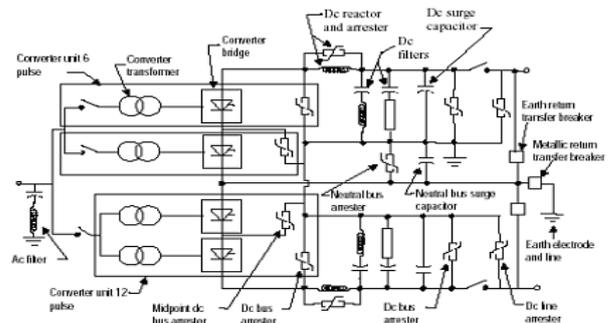


Fig. 1.6. HVDC substation configuration

1.3.2 Converter Transformer: The arrangement of the transformer windings depends on the converter configuration. For example the 12-pulse converter configuration can be obtained with any of the following transformer arrangements [2]:

- Six single-phase, two winding
- Three single-phase, three winding
- Two three-phase, two winding

1.3.3 Smoothing Reactors: The main purpose of a smoothing reactor is to reduce the rate of rise of the direct current following disturbances on either side of the converter [2].

1.3.4 AC Filters: Filters are used to control the harmonics in the network.

1.3.5 DC Filters: The harmonics created by the converter can cause disturbances in telecommunication systems and specially designed DC filters are used in order to reduce the disturbances.

1.3.6 Transmission medium: HVDC cables are generally used for submarine transmission and overheads lines are used for bulk power transmission over the land.

1.3.7 HVDC TECHNOLOGY: The fundamental process that occurs in an HVDC is the conversion of electrical current from ac to DC (rectifier) at the transmitting end and from DC to ac at the receiving end.

1.4 SELECTION OF CONVERTER CONFIGURATION:

Introduction: A DC system can be operated with constant voltage or with constant current. In this the selection of converter configuration

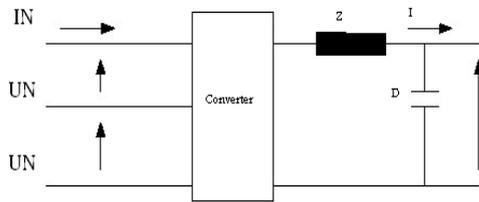


Fig. 1.7. Current converter

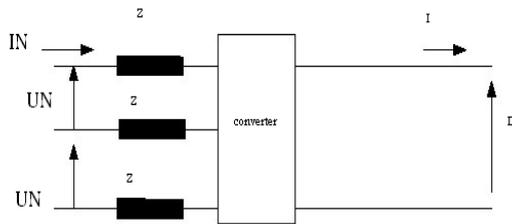


Fig. 1.8. Voltage converter

The voltage can still be regulated using the devices and the current ratio remains unaltered. The converter configuration as shown in fig.1.4, has an impedance Z connected across. Again there are three different combinations of voltage and current source converters.

- a) Voltage source converters on both ends
- b) Voltage source converter on one end and current source on other end
- c) Current source converters on both ends.

a) Natural Commutated Converters: These are most used in the HVDC systems as of today. The component that enables this conversion process is the thyristor.

b) Capacitor Commutated Converters: The capacitors are connected in series between the converter transformer and the thyristor valves.

c) Forced Commutated Converters: This type of converters is advantageous in many ways. For the control of active and reactive power, high power quality etc.,

1.5 CONVERTER OPERATION:

The six-pulse converter bridge shown in the fig.1.5 is used as the basic converter unit of HVDC transmission rectification where electric power flows from the ac side to the DC side and inversion where the power flow is vice versa. Thyristor valves conduct current on receiving a gate pulse in the forward biased mode. The thyristor has unidirectional current conduction control and can be turned off only if the current goes to zero in the reverse bias. This process is known as line commutation. Inadvertent turn-on of a thyristor valve

may occur once its conducting current falls to zero when it is reverse biased and the gate pulse is removed. Too rapid an increase in the magnitude of the forward biased voltage will cause the thyristor to inadvertently turn on and conduct [1]. The design of the thyristor valve and converter bridge must ensure such a condition is avoided for useful inverter operation.

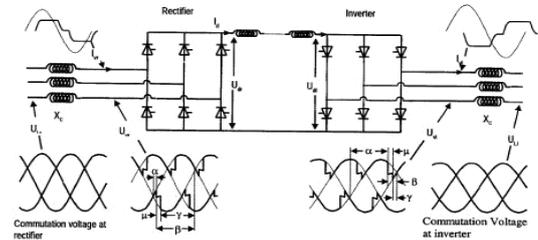


Fig. 1.9. HVDC operation

a) Commutation: Commutation is the process of transfer of current between any two-converter valves with both valves carrying current simultaneously during this process [1].

b) Converter Bridge Angles: The electrical angles, which describe the converter bridge operation, are shown in fig. 1.9.

c) Delay angle alpha (α): This angle is controlled by the gate firing pulse and if less than 90 degrees, the converter bridge is a rectifier and if greater than 90 degrees, it is an inverter. This angle is often referred to as the firing angle.

d) Advance angle beta (β): The time expressed in electrical angular measure from the starting instant of forward current conduction to the next zero crossing of the idealized sinusoidal commutating voltage. The angle of advance β is related in degrees to the angle of delay ‘α’ by:

$$\beta = 180 - \alpha$$

e) Overlap angle (μ): The duration of commutation between two converter valves expressed in electrical angular measure.

f) Extinction angle gamma (γ):Gamma (γ) depends on the angle of advance β and the angle of overlap μ and is determined by the relation

$$\gamma = \beta - \mu$$

1.6 Control and Protection: HVDC transmission systems involve (must transport) very large amounts of electric power and the desired power transfer is achieved by precisely controlled DC current and voltage across the system. Also in DC transmission the power-flow direction is determined by the relative voltage magnitudes at the converter terminals which can be controlled by adopting a firing-angle control scheme. Therefore it is very important and necessary to continuously and precisely measure system quantities which include at each converter bridge, the DC current, its DC side voltage the delay angle α and for an inverter, its extinction angle γ. Each converter station is assumed to be provided with constant current and constant extinction-angle controls for equidistant firing angle control.

II. POWER QUALITY

2.1 INTRODUCTION:

Large amount of harmonics, poor power factor and high total harmonic distortion (THD) in the utility interface are common problems when non-linear loads such as adjustable

speed drives, power supplies, induction heating systems, UPS systems and SMPS are connected to the electric utility. In several cases, the interface to the electric utility is processed with three-phase uncontrolled diode bridge rectifier. Due to the nonlinear nature of load, the input line currents have significant harmonics.

2.2 POWER QUALITY PROBLEM:

The power quality of power supply of an ideal power system means to supply electric energy with perfect sinusoidal wave form at a constant frequency of a specified voltage with least amount of disturbances. However the harmonic is one of the major factor due to which none of condition is fulfilled in practice. The presence of harmonics disturbs the waveform shape of voltage and current and increases the current level and changes the power factor of supply and which in turn creates so many problems.

2.3 WHAT ARE HARMONICS?

The electricity is produced and distributed in its fundamental form as 50 Hz in India. A harmonics is defined as the content of signal whose frequency is integral multiple of the system fundamental frequency. Due to harmonic effect the sinusoidal wave form is no longer have stand and it become non-sinusoidal or complex wave form. The complex waveform consists of a fundamental wave of 50 Hz and a number of other sinusoidal waves whose frequencies are integral multiple of fundamental wave like 2f(100hz), 3f (150 Hz), 4f (200 Hz) etc. Wave having frequency of 2f, 4f, 6f etc are called the even harmonics and those having frequency of 3f, 5f, 7f etc are called as odd harmonics. When fundamental frequency is super imposed with high-level harmonics it results into complex wave and which is non sinusoidal.

2.4 CAUSES OF PRODUCTION OF HARMONICS:

There are many cases which are responsible for production of harmonic effect in power supply system, few of them listed below:

- More use of solid-state power converters for industrial drivers.
- Use of arc and induction furnaces for steel and non-ferrous plants.
- Use of thyristor controlled locomotives.
- Use of electronic loads in domestic sectors.
- Use of energy conservation devices in both domestic and industrial sectors, e.g. electronic chokes for florescent light, electronic controllers for motors.
- The operation of transformers closure to saturation region for magnetizing curve.
- Non-sinusoidal air gap flux in synchronous machines.
- Magnetizing current of saturated reactors.

2.5 EFFECTS OF HARMONICS ON ELECTRICAL EQUIPMENTS:

Few cases in that how electrical equipments and circuits affect due to presence of harmonics in power supply system.

- When complex voltage is applied across circuit containing both inductance and capacitance, it may happen that circuit resonate at one of the harmonic frequencies of applied voltage. If it is a series circuit large current will be produced at resonance, even though the applied voltage

due to harmonic may be small. If it is a parallel circuit then at resonant frequency the resultant current drawn from the supply would be minimum.

2.6 Review of Multi-Pulse Converters:

- A large number of publications have appeared in the field of multi-pulse converters, many giving new concepts and verifying their claims by simulations and experimental work. Paice [1] proposed maximizing the efficiency of a 12 pulse AC-DC converter based on a hexagonal autotransformer arrangement. Choi [2] in his paper has presented new autotransformer arrangements with reduced KVA capacities are presented for harmonic current reduction and to improve AC power quality of high current DC power supplies. Simulation results are given in the paper. Falcondes and Babri[3] has proposed a new isolated high power factor 12 KW power supply based on 18-pulse transformer arrangement .the topology used involves a simple control strategy .simulations and experimental results are given in paper.

II. MULTI-PULSE CONVERTERS

As it has been mentioned earlier, there are several techniques primarily adopted for the mitigation of harmonics in a 3-phase converter and multi-pulse converters fall in the same category of remedial measures. This technique is discussed, in detail, in the present chapter.

3.1 INTRODUCTION:

As it has been emphasized already, AC/DC converters in various drive and other industrial applications are the root cause for power quality problems. As the research in high energy physics progresses and as the particle accelerators find many applications in industrial and medical areas, power supplies with integrated magnetics featuring high input power quality and better performance are increasing in demand. In non isolated multi-pulse converters, the windings are interconnected such that the kVA transmitted by the actual magnetic coupling is only a portion of total kVA. The reduction in kVA rating of the transformer and a new method to improve the quality of AC input currents by introducing taps on the interphase reactor has also been proposed in the literature.

3.2 MULTI-PULSE METHODS:

The term multi-pulse method is not defined precisely. In principle, it could be imagined to be simply more than one pulse. However, by proper usage in the power electronics industry, it has come to mean converters operating in a three phase system providing more than six pulse of DC per cycle.

Multi-pulse systems result in two major accomplishments namely,

1. Reduction of ac input line current harmonics.
- 2.Reduction of DC output voltage ripple`

3.2.1. Un controlled Multipulse Converters:

Fig.3.1. to Fig 3.3. Shows some of the circuits of these converters. Normally, diode bridges are used with a higher number of pulses for reducing harmonics in ac mains and reduced value of ripple voltage in the dc output. These are developed in 12-, 18-, 24-, 30-, 36-, 48-pulse,

etc., converters, through input multi pulse auto/isolation transformers.

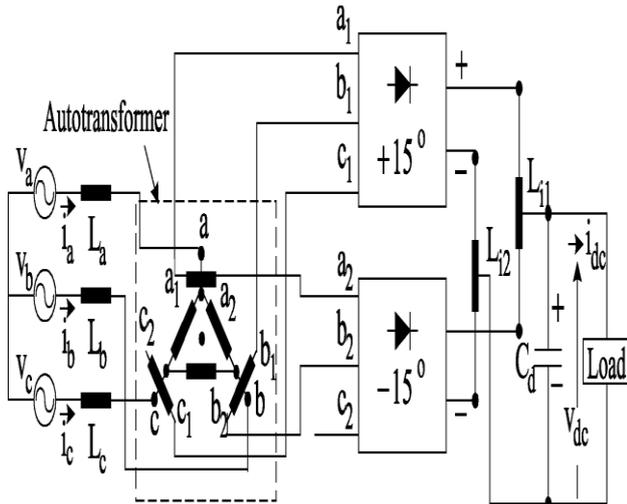


Fig.3.1. Un controlled 12 pulse converter

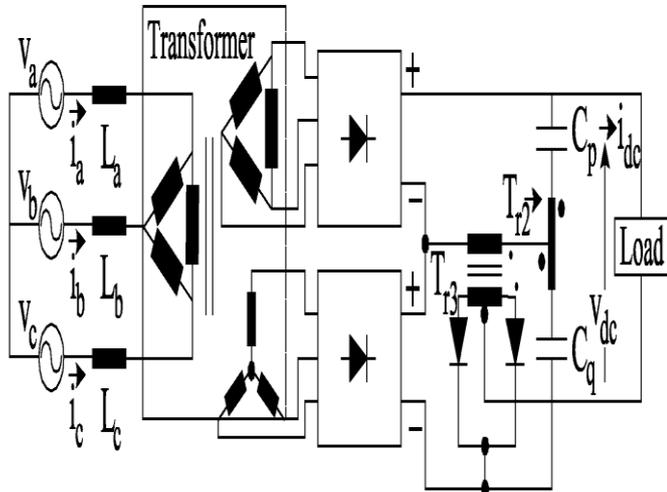


Fig.3.3. Un controlled 24 pulse converter

3.2.2. Controlled Multipulse Converters:

These converters normally use thyristors and harmonics reduction is made effective with pulse multiplication using magnetics. Fig. 3.4 & 3.5 shows the two typical circuits of such converters. The use of fully controlled thyristor bridge converters offers bidirectional power flow and adjustable output dc voltage. The use of a higher number of phases through an input multiple winding transformer and pulse multiplication using tapped reactor, and an injection transformer, reduces THD to input ac currents and ripples in the output dc voltage. These converters are used in high rating dc motor drives, HVdc transmission systems, and in some typical power supplies. Fig.3.4. shows a typical multipulse converter, which can be operated as a 6-, 12-, and 24-pulse converter. Similarly, the converter shown in Fig. 3.5. can be operated in 12-, 24-, and 48-pulse modes of operation. The cost and weight of input transformers can be reduced by using autotransformers in low-and medium-voltage applications.

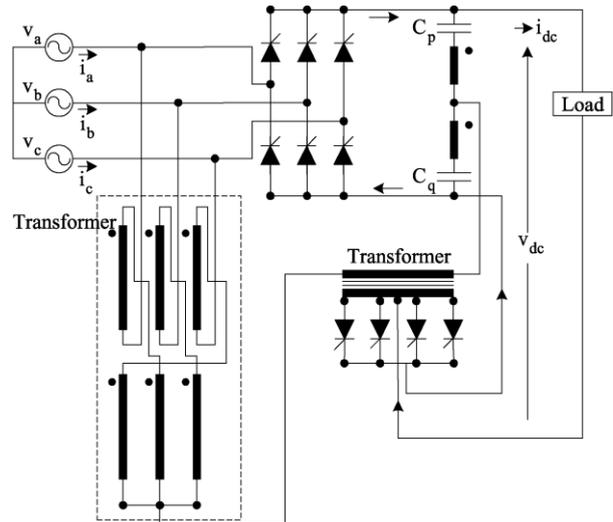


Fig.3.4. 24 pulse controlled midpoint reactor converter

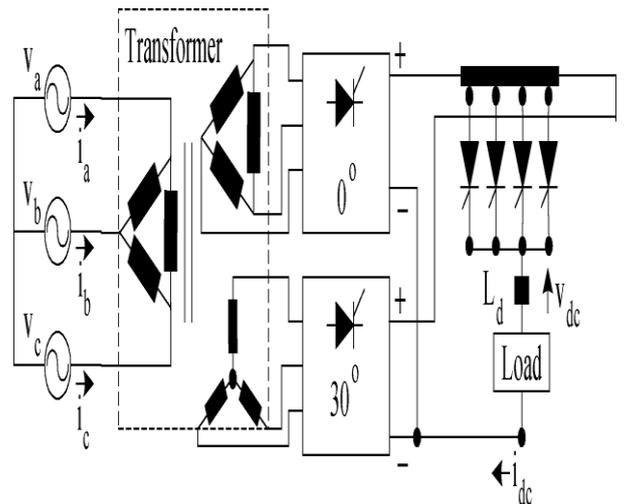


Fig.3.5. 48 pulse controlled converter

3.3 ZIG-ZAG PHASE SHIFTING TRANSFORMERS:

The Zigzag Phase-Shifting Transformer implements a three-phase transformer with a primary winding connected in a zigzag configuration and a configurable secondary winding. The model uses three single-phase, three-winding transformers. The primary winding connects the windings 1 and 2 of the single-phase transformers in a zigzag configuration.

IV. SIMULINK/MATLAB AS A TOOL FOR SIMULATION

Simulation is a tool for the understanding of many complex problems. Several digital simulation packages are commercially available. This chapter presents a comparison of the salient features of various simulation tools available to model the electrical drive systems in a digital computer such as PSIM, CASPOC, PSPICE, SABER, SIMPLORER and SIMULINK/MATLAB.

PSPICE is mainly meant for the simulation of electronic circuits. Modeling of machines especially with a feedback control loop becomes very difficult in this package. PSIM and CASPOC take very little time to learn but the

micro-modeling of devices is not possible in this package due to which the accuracy of results is quite limited. SABER and SIMPLORER are exclusively meant for power electronic and drive system simulations and they are user-friendly as well. But both these packages are extremely expensive. SIMULINK/MATLAB is a general-purpose simulation tool with several tool-boxes embedded in it to enable modeling of complicated control schemes as well. The power system block set has specifically a large number of components conforming to the needs of an electrical power engineer.

V. SIMULATION OF CONTROLLED AND UNCONTROLLED MULTI-PULSE AC-DC CONVERTERS

5.1 SIMULATION OF UNCONTROLLED MULTI-PULSE CONVERTERS:

5.1.1 Six-pulse converter (un-controlled)

The six pulse converter bridge shown in Fig. as the basic converter unit of HVDC transmission is used equally well for rectification where electric power flows from the a.c. side to the d.c side and inversion where the power flow is from the d.c side to the a.c. side. Thyristor valves operate as switches which turn on and conduct current when fired on receiving a gate pulse and are forward biased.

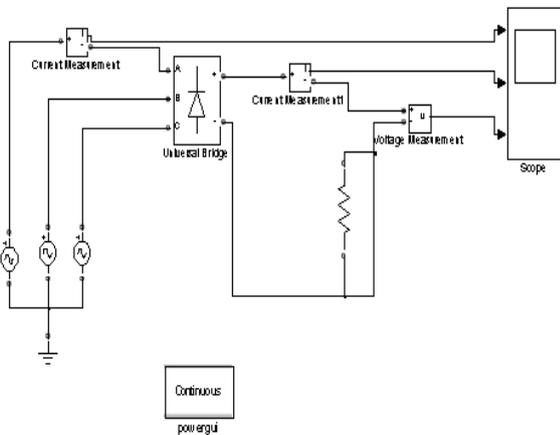


Fig. 5.1. Uncontrolled Six-Pulse Converter

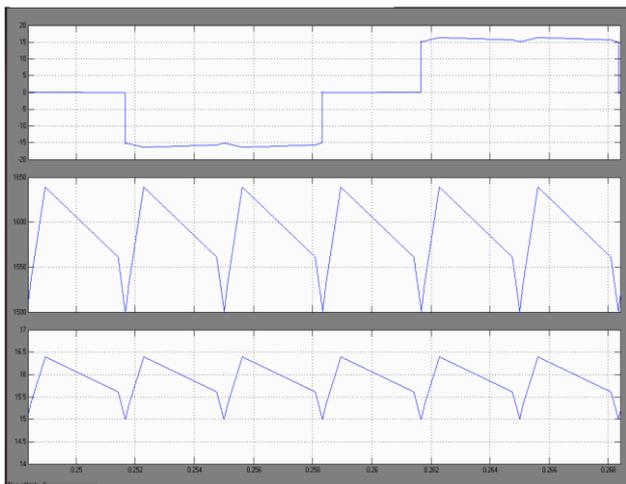


Fig. 5.2. Waveforms of input current, output voltage, output current:

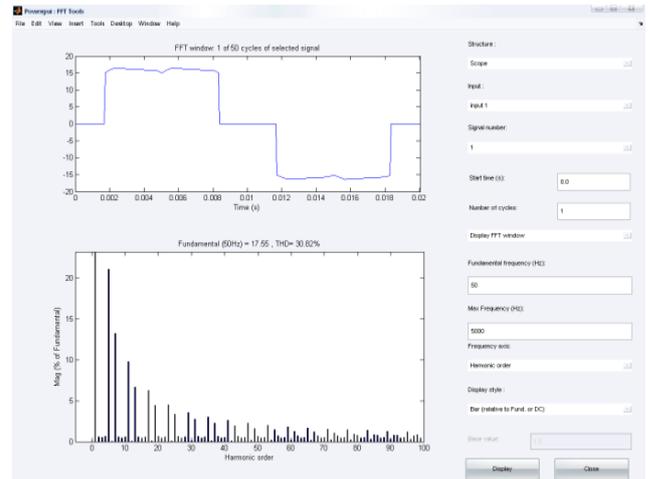


Fig. 5.3. THD for input current



Fig. 5.4. THD for output voltage

5.1.2 Simulation of Controlled Multi-Pulse Converters:

For the simulation of controlled multi pulse converters instead of the diode bridge we use the thyristor bridge and the corresponding pulses are given.

5.4.1 Six-pulse converter (controlled)

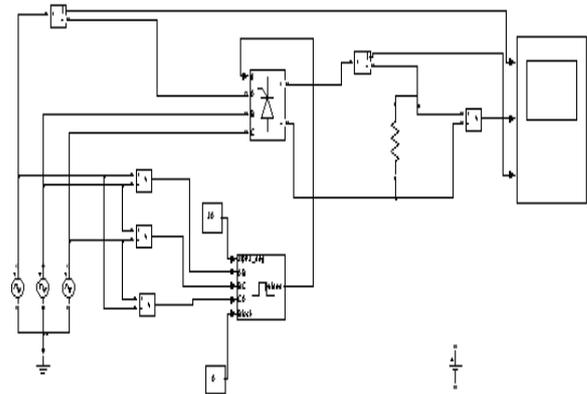


Fig. 5.25. Controlled six-pulse Converter

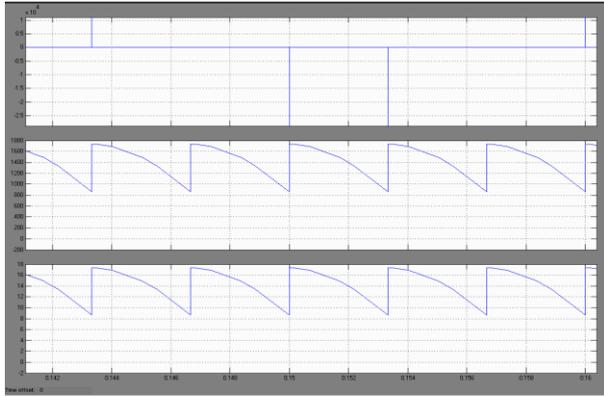


Fig. 5.26. Output waveform of input current, output voltage, output current

VI.CONCLUSION

The main objective of this work is to investigate the performance of controlled and un-controlled multi-pulse converters. These converters are studied in terms of harmonic spectrum of ac mains current, THD, distortion factor, displacement power factor and actual power factor in the AC mains. It is concluded therefore that in general with increase in number of pulses in multi-pulse case the performance parameters of these converters are remarkably improved.

VII.REFERENCES

- i. D.A.Paice. "Auto connected hexagon transformer for a 12-pulse converter". Patent number: 5148357. 1992.
- ii. Choi dewan, enjeti, pittel "autotransformer configurations to enhance utility power quality of high power AC/DC rectifier systems."1996 IEEE
- iii. Babri Ivoand Jones, "a new three -phase low THD supply with High -frequency isolation and 60v/200A regulated DC supply". 2001. IEEE
- iv. S.Kim, Enjeti, "A new approach to improve Power Factor and reduce Harmonics in a Three-Phase Diode Rectifier Type Utility Interface"IEEE trans.on Industry appl,Vol.30,No.6,NOV/DEC 1994.
- v. Chen and Hong, "A new passive 28-step current shaper for three-phase rectification."IEEE transactions on industrial electronics, vol.47, No.6, December 2000.
- vi. N.R.Zargari etal, "A multilevel thyristor Rectifier with improved power factor" IEEE trans.on industry applications, vol.33.No.5, SEPT/OCT. 1997 D.A.Paice, Power Electronic Converter Harmonics- Multipulse Methods for Clean Power. New York: IEEE Press, 1996.
- vii. N.Mohan, TUDeland and W.Robbins, Power Electronics: Converters, Applications

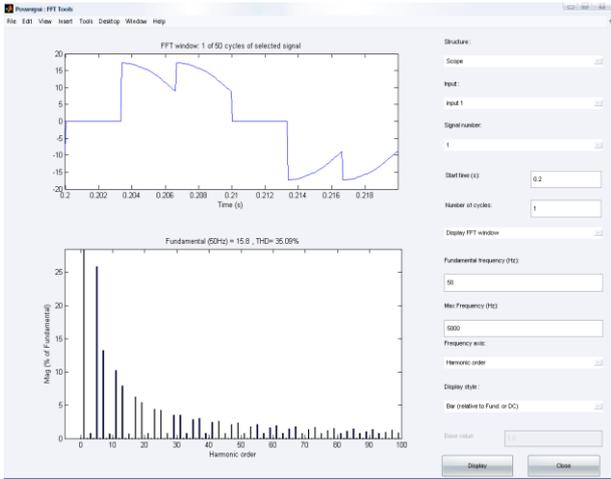


Fig. 5.27. THD for input current

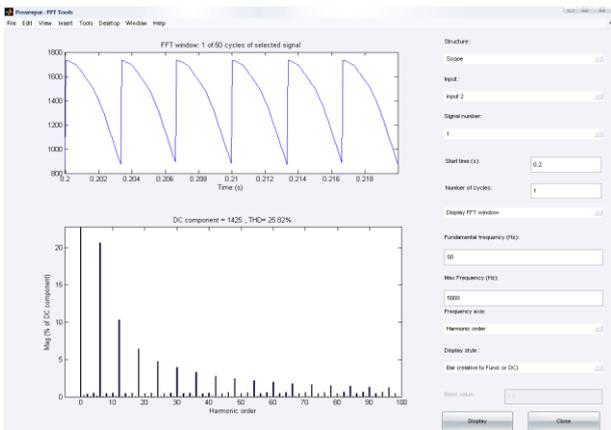


Fig. 5.28. THD for output voltage