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Total Harmonic Reduction by Multi Pulse Converters

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***Abstract* - The issue of power quality now a days is a major concerned area of research in the power sector. This is because of awareness created by IEEE 519-1992(Institute of Electrical & Electronics Engineering) like standards which implies the utility as well as consumers of electric power to improve quality. With the advancement in the technology now it is possible to keep power sector free from pollution. This paper has given an idea that power quality can be improved with development of multi pulse converter, Here 6,12,24,48 pulse converters have been modeled and simulated in MATLAB software. The multi pulse converters are tested for different loads and comparison is also presented among them which clearly shows that the problem of power quality is reduced considerably.**

***Index Terms* - THD, Multi pulse converter, Power Quality, Harmonics, High Power Drives.**

I.INTRODUCTION

AC-DC converters are widely used in a number of applications such as adjustable speed drives (ASDs), high voltage dc (HVDC) transmission, electro-chemical processes such as electroplating, telecommunication power supplies, battery charging, UPS, high-capacity magnet power supplies, high power induction heating equipment, aircraft converter systems, plasma power supplies and converters for renewable energy conversion system. The use of converters and other solid-state devices to control the power flow deteriorates the power quality. A lot of research has already been done on the topologies and modulation strategies of AC-DC converters. The main issues in designing these converters for specific applications are harmonic distortion in output voltage and supply current , load power factor, efficiency, switching losses, real and reactive power capability etc. a large series inductor is placed in the dc circuit to lower the ripple content of current which in turn helps to limit harmonic distortion in the AC current. Harmonics are non-sinusoidal voltages or currents having frequencies that are integer multiples (Typical Harmonics are the 3rd, 5th, and 7th. 3rd = 150 Hz 5th = 250 Hz 7th = 350 Hz), of the fundamental frequency at which the supply system is designed to operate, that combine with the fundamental voltage or current, and produce waveform distortion.

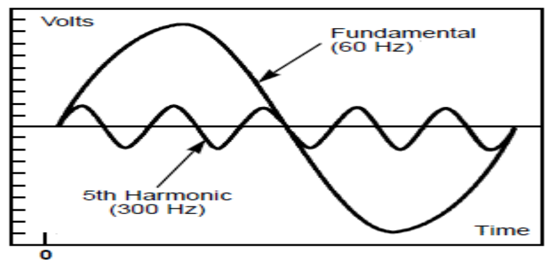


Fig.1 Harmonic distortion waveform

Effect of Harmonic, over-heating of Transformers, Resonance Circuit with Capacitors Parallel/ Series, Malfunction of Equipment, UPS alarm. Present research trend is towards improving the power quality of these converters. According to IEEE standards 519-1992 harmonic contents should be less than 5%, so to meet the IEEE 519 standards. Power quality is to be improved in terms of improved power factor, reduced Total Harmonic Distortion (THD), reduced switching losses etc. These improvements can be achieved by selecting the appropriate technique of various power devices in the converters. Power quality means the quality of power which we are receiving from utility. All the above mentions performance indices are meant for power quality improvement. A better strategy for that will be to use multiple pulse converters. In multiple pulse converters output voltage will be very near to sine wave as desired. These types of converters are used in high power (upto 200MVA) flexible AC transmission systems (FACTS) which are used to control power flow on transmission grids. It can be used to built a model of shunt or series static compensator (STATCOM or SSSC) or using two such converters, a combination of shunt and series devices known as Unified Power Controller (UPFC).In this paper modeling and simulation of multi-pulse converters is presented. A comparison among these converters has been presented based on the output voltage and input current waveforms, total harmonic distortion in output voltage and input current, load power factor and switching losses.

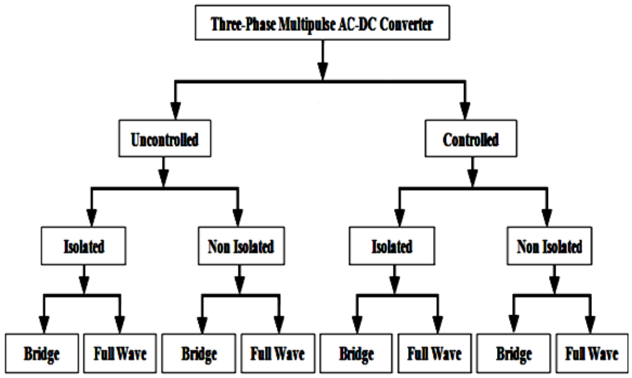


Fig.2 Classification of three phase multi-pulse converters

CLASSIFICATION OF 3-PHASE MULTI-PULSE AC-DC CONVERTER

The performance is investigated for the following multi pulse converters.

1. 6 Pulse uncontrolled converters
2. 12 Pulse uncontrolled converters
3. 24 Pulse uncontrolled converters
4. 48 Pulse uncontrolled converters

All the simulations have been carried out for the above mention multi-pulse converters in MATLAB Simulink. Power System blocked environment. Simulation study have been carried out by varying circuit parameters i.e. load power factor, switching frequency etc.

II.SIMULATION OF MULTI-PULSE CONVERTERS

(a) 6-PULSE CONVERTER

MATHEMATICAL MODEL OF SIX-PULSE RECTIFIRE

A Six-pulse diode rectifier feeding R-L load & pertains to the circuit modal of six-pulse thyristor rectifier feeding on R-L load. The three phase input supply voltage (V_{an}, V_{bn}, V_{cn}) without line impedance drop could be expressed as

$$V_{an} = V_m sin\omega t$$

$$V_{bn} = V_m sin(\omega t - \frac{2\pi}{3})$$

$$V_{cn} = V_m sin(\omega t + \frac{2\pi}{3})$$

The source voltage of three phases a, b, c at the input of rectifier (V_{sa}, V_{sb}, and V_{sc}) can be expressed in equation as

$$V_{sa} = V_{an} - R_s. I_{sa} - L_s \frac{di_{sa}}{dt}$$

$$V_{sb} = V_{bn} - R_s. I_{sb} - L_s \frac{di_{sb}}{dt}$$

$$V_{sc} = V_{cn} - R_s. I_{sc} - L_s \frac{di_{sc}}{dt}$$

Where I_{sa}, I_{sb}, I_{sc} are the rectifier input current & R_s & L_s are the source resistance & inductance respectively. In this circuit when diode pair conducting for each 60^0 interval, the value for the phase current I_{sa}, I_{sb}, I_{sc} are specified as being zero. The load current i_L or the negative current ($-I_L$), and the three phase supply current (I_{sa}, I_{sb}, I_{sc}) can be determined for this input current for this conduction interval of diode pair (D_1D_2, D_2D_3, D_3D_4, D_4D_5, D_5D_6, and D_6D_1)with 60^0 duration for an interval.

$$V_{do} = \frac{3\sqrt{2}}{\pi} V_{LL}$$

where V_{LL} is the line voltage (rms)

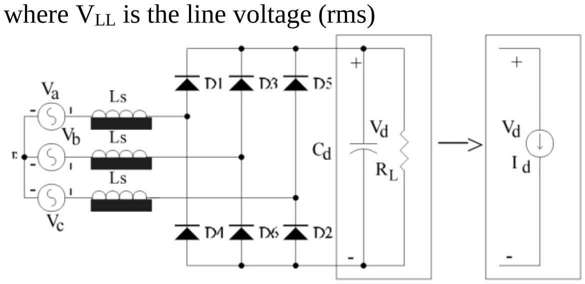


Fig.3 Six pulse-converter diode rectifier with R-load.

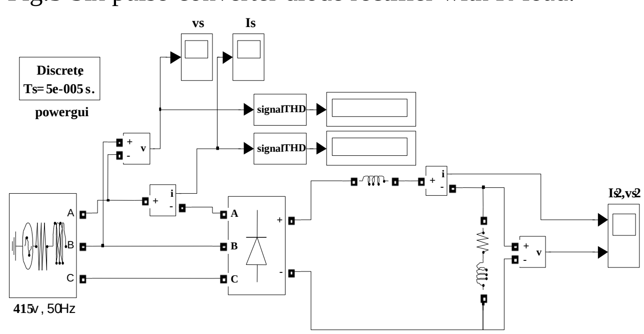


Fig.4 Simulation model of the six pulse diode rectifier with R-L load

The output voltage of a six pulse converter consists of an average value plus a number of harmonics of the order 6f, 12f, 18f etc, where f=fundamental frequency. Higher number of pulses can be obtained by connecting two or more six pulse converters in series or in parallel according to our voltage or current requirement.

(b) 12-PULSE AC/DC CONVERTER

In this work, 12-pulse converter is obtained by connecting two six pulse converters in series with primary connected in star connection. Fig.5 clearly indicates improved waveforms of rectifier output variables. Current has been smoothened by a good amount. The primary of transformers can be connected either in star or in delta.

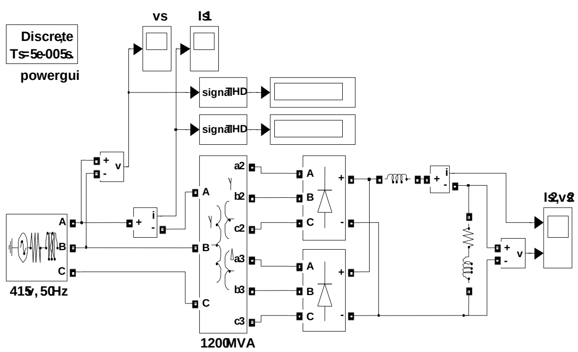


Fig.5 MATLAB simulation model of 12-pulse converter

Since each converter gives a 6-pulse output, the resultant voltage is a 12-pulse output through the two converters. However, the supply current waveform for a particular connection remains the same as the firing angle is varied. In the star-connected secondary winding, the line currents are 120^0 width pulses with constant amplitude. A 12 pulse converter has 12 ripple pulses per fundamental ac cycle. Each fully controlled converter is a three phase bride consisting of six Thyristors. The three phase voltages supplying the two bridges are displaced by a phase angle of 30^0 degrees and hence the two 6 pulse output are symmetrically displaced to give an overall 12 pulse output. Because of the series connection of the converters, the total output voltage is the sum of the individual converter output voltage, so

$V_o = V_{o1} + V_{o2}$

The voltage and current waveforms at output side of converter are smooth due to smoothing inductance. Because of series connection current will be same for both the converters. The voltage and current waveforms are drawn for a firing angle of 45^0 degrees. In order to make voltage output of the converters the same, a turn ratio of 3 is necessary between the windings of the star and delta secondary's. The line current for each converter is a square wave of magnitude I_a and width 120^o.

The main point in designing the multiple pulse converters is to obtain exact phase angle between different secondary windings of transformer. Different connections of transformers for 24-four pulse rectifier are shown in fig.6. Two 12-pulse converters, phase shifted by 15^0 degrees from each other, can provide a 24-pulse converter, obviously with much lower harmonics on ac and dc side. Its ac output voltage would have (24p+1)order harmonics i.e., 23^{rd}, 25^{th}, 47^{th}, 49^{th}…..harmonics, with magnitudes of $1/23^{rd}$, $1/25^{th}$, $1/47^{th}$, $1/49^{th}$…..., respectively of the fundamental ac voltage where p is the number of pulse. This 15^0 degrees phase shift can be achieved in two ways. One approach is to provide 15^0 degrees phase-shift windings on the two transformers of one of the 12-pulse converters. Another approach is to provide phase-shift windings for $+7.5^0$ degrees phase shift on the two transformers of one 12-pulse converters. The latter is preferred because it requires transformers of the same design and leakage inductances. It is also necessary to shift the firing pulses of one 12-pulse converter by 15^0 degrees with respect to the other. All four six-pulse converters can be connected on the dc side in parallel. Alternately all four six-pulse converters can be connected in series for high voltage, or two pair of 12-pulse series converters may then be connected in parallel. Each six-pulse converter will have a separate transformer, two with star-connected secondary and the other two with delta-connected secondary. Primaries of all four transformers can be connected in series in order to avoid harmonic circulation current corresponding 12-pulse order, i.e. 11^{th}, 13^{th}, 23^{rd}, 24^{th}.It may be worthwhile to consider two 12-pulse converters connected in parallel on the ac system bus bars, with inter phase reactors as shown in fig.6, for a penalty of small harmonic circulation inside the converter loop. While this may be manageable form the point of view of converter rating, care has to be exercised in the design of the converter controls, particularly during light load when the harmonic currents could become the significant part of the ac current flowing through the converter. An increase in the transformer impedance to, say, 0.2 per unit may be appropriate when connecting two- 12-pulse transformers to the ac bus directly and less than that when connected through inter phase reactors.

Different connections of transformer

(c) 24-PULSE AC-DC CONVERTER

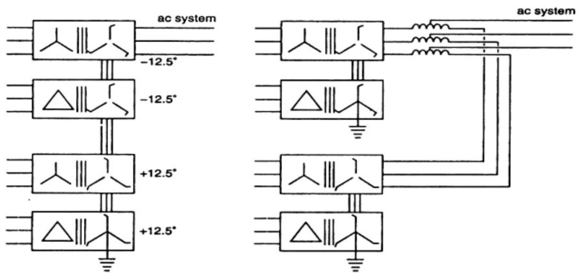


Fig.6 MATLAB Simulation Model of 24-pulse converter

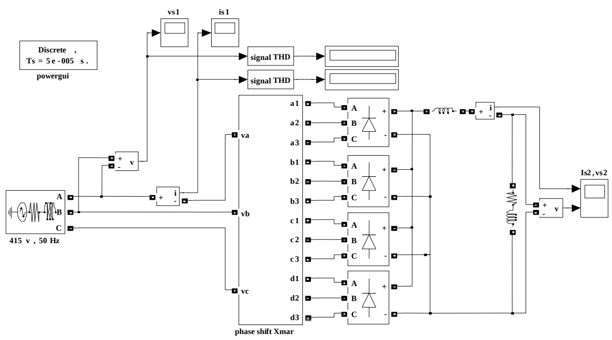


Fig.7 MATLAB simulation model of 24-pulse converter

(d) 48-Pulse Converter

It is developed by connecting two 24 pulse converter in series or in parallel according to our current or voltage requirement.

MATLAB Simulation Model of 48-pulse converter

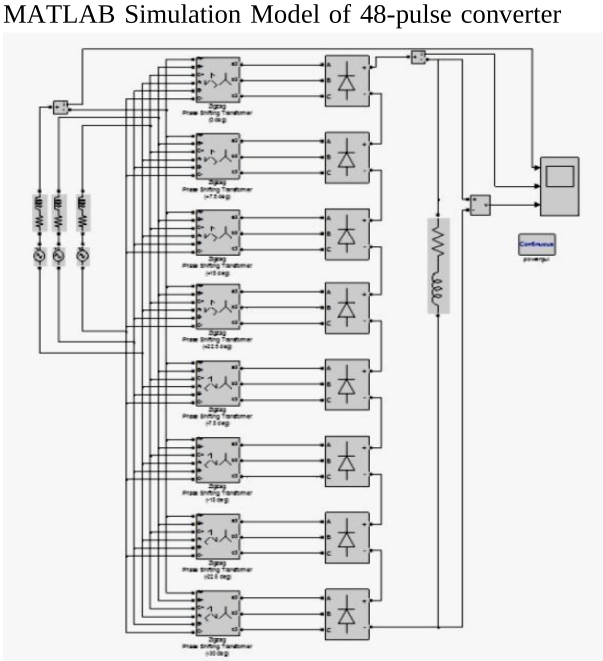
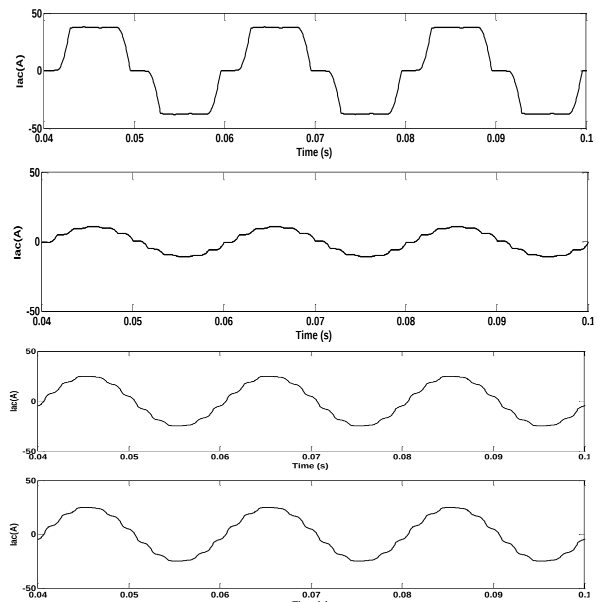


Fig.8 MATLAB simulation model of 48-pulse converter

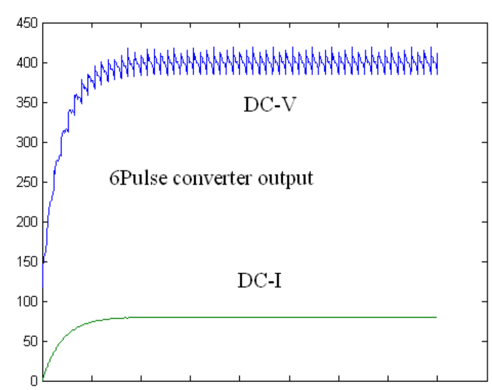
FINAL COMPARISON OF MULTI-PULSE CONVERTER

Multi-pulse converters are one of the measures to improve power quality of electrical system. If above multi-pulse converters are compared, as shown in fig it is seen that current profile has been improved significantly. Total harmonic distortion is reduced. Fig shows output voltages of 6, 12, and 24-pulse converters. It signifies that ripples in output voltage are decreasing with the number of pulses and so the voltage harmonics. It can be seen that THD of twenty four pulse converter is lesser compared to six pulse rectifiers. Fig shows variation of THD with percentage load for the multi-pulse converters considered for study.

Comparison of AC Input current wave form of 6, 12, 24, 48- pulse converters



Comparison of DC output wave form of 6, 12, 24, 48- pulse converters



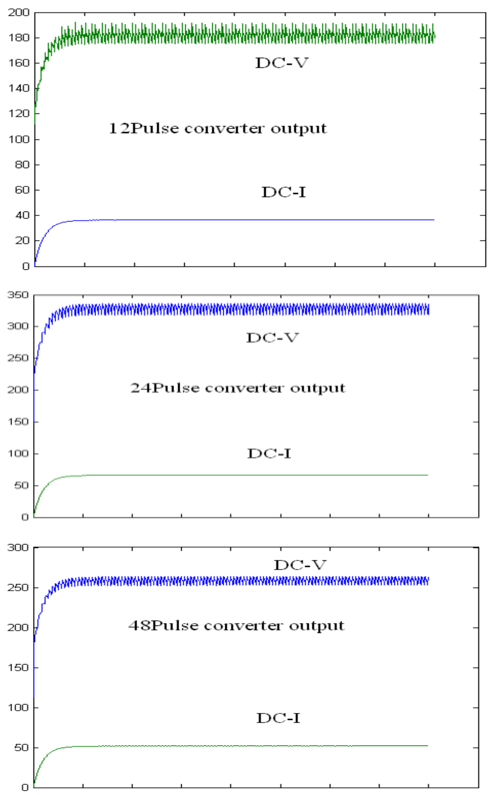


Table: Power quality indices of multi pulse AC-DC converter with RL load

Different Multi Pulse converter	% of load	% THD of I_{ac}	Output Voltage V_{dc}	PF
6-Pulse	100%	16.99	301.1	0.993
12-Pulse	100%	6.11	180.1.	0.988
24-Pulse	100%	3.56	263.2	0.992
48-Pulse	100%	2.87	263.2	0.996

CONCLUSION

For high-power FACTS controllers, from the point of view of the ac system, even a 24-pulse converter without ac filters could have voltage harmonics, which are higher than the acceptable level. In this case, a single high pass filter tuned to the 23rd-25th harmonics located on the system side of the converter transformers should be adequate. The various performance characteristics of different multi-pulse converters are obtained from the simulation. With the increase in the number of pulses harmonics are reduced considerably. This has been seen in different results as obtained from the simulation. Compared to six pulse thyristor converter, twelve pulse thyristor converters have lesser harmonics. Similarly from the simulation results eighteen pulse converter has still lesser harmonics than twelve pulse converter and still lesser in twenty-four pulse thyristor converter. So it can be concluded that there will be a progressive decrease in harmonics as the number of pulses are increased. In other words, according to IEEE-519-1992 standard for maintaining good quality of power at utility as well as consumer end, multi-pulse converter may be a good solution.

In order to increase the number of pulses in the converter circuit additional bridges and the corresponding phase shifting transformers are required due to which the VA rating of drives is increased. It can be used for large range with the same model.

Converters are increased and it increases the cost of equipment. This technique has many operational benefits over thyristor rectifiers such as low output ripple test dynamic response, higher system efficiency, minimal harmonic distortion, less switching losses etc. This technique can be used for large range with the same model. External auxiliary equipments are reduced with this scheme.

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