Analysis of Multi-Pulse Converters for Harmonic Reduction

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Abstract— This research paper deals with the reduction of Total Harmonic Distortion using Multi-pulse AC to DC Conversion scheme. The three-phase multi-pulse AC to DC conversion system employs a phase-shifting transformer and a three-phase. Every such converter provides 6-pulse AC to DC conversion, so in order to produce more sets of 6-pulse systems, a uniform phase-shift is required and hence with proper phase-shifting angle, 12, 18, 24, 30, and higher pulse systems have been produced. The performance improvement of multi-pulse converter is achieved for total harmonics distortion (THD) in supply current, DC voltage ripples and form factor. All the simulations have been done for similar ratings for all the multi-pulse converters configurations. The results are obtained for both uncontrolled and controlled converters for R, RL and RC Load.

Keywords: Multipulse, Total Harmonic Distortion, Form factor, Ripple Content, 6-pulse, 12-pulse, 18-pulse, 36-pulse, 48-pulse

I. INTRODUCTION

In the past few years a lot of work has been done for the reduction of Total Harmonic Distortion using different concepts and applications. This thesis work deals with the reduction of Total Harmonic Distortion using Multi-pulse AC to DC Conversion scheme. The results are obtained for both uncontrolled and controlled converters for R, RL & RC Load.

The three-phase multi-pulse AC to DC conversion system employs a phase-shifting transformer and a three-phase converter between the supply and load side of the system. Every such converter provides 6-pulse AC to DC conversion, so in order to produce more sets of 6-pulse systems, a uniform phase-shift is required and hence with proper phase-shifting angle, 12, 18, 24, 30, and higher pulse systems can be produced.

Different rectifiers are used for conversion of AC supply into DC supply. For uncontrolled conversion, diodes have been preferred, while for the controlled conversion, thyristors have been implemented.

The performance improvement of multi-pulse converter is achieved for total harmonics distortion (THD) in supply current, DC voltage ripples and form factor. All the simulations have been done for similar ratings of RL Load, for all the multi-pulse converters configurations, so as to represent a fair comparison among controlled and uncontrolled continuations of multi-pulse converters.

The presented simulation results show the reduced THD at supply side. These results agree with the IEEE Standards 519-1992. Effect of increase in number of pulses in converter circuits for uncontrolled and controlled multipulse converter on input supply current and DC side voltage and current has been presented in this work [1].

II. OBJECTIVE OF PRESENT STUDY

The present work is an effort 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 has been analyzed. For performance comparison the major factors considered are the ripple percentage, form factor and the total harmonic distortion (THD). The effects of load variation on multi-pulse AC to DC converters have also been investigated[2].

III. MULTI-PULSE METHODS

Multi-pulse methods involve multiple converters connected so that the harmonics generated by one converter are cancelled by harmonics produced by other converters. By this means, certain harmonics related to number of converters are eliminated from the power source. In multi-pulse converters, reduction of AC input line current harmonics is important as regards to the impact the converter has on the power system[3].

Multi-pulse methods are characterized by the use of multiple converters or multiple semiconductor devices with a common load.

Fig. 1 & Fig. 2 given below depict the various techniques used widely for the reduction of harmonics[4].

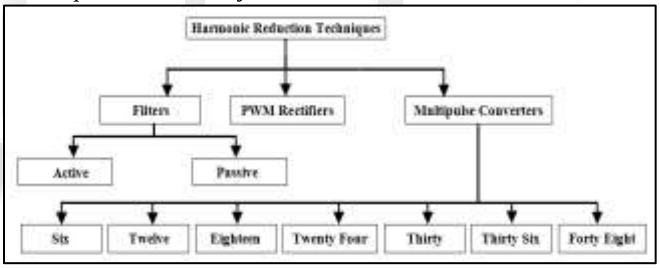


Fig. 1: Various Harmonic Reduction Techniques

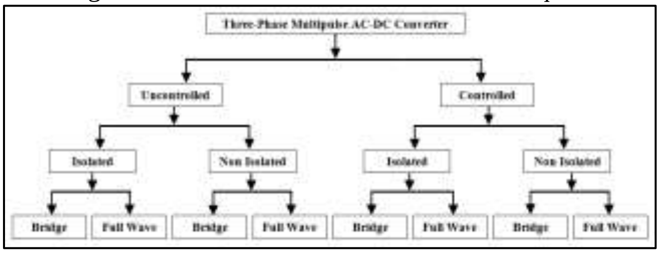


Fig. 2: Multi-Pulse Converter Configurations

For the ease & convenience model & FFT analysis for RL load only, have been provided in the adjoining text.

IV. SIMULATION OF UNCONTROLLED MULTI-PULSE CONVERTERS

A. *Six-Pulse Converter*

The six pulse converter bridge shown in Fig 3. as the basic converter unit of HVDC transmission is used for rectification, where electrical power flows from the AC side to the DC side and inversion where the power flow is from the DC side to the AC side. Thyristor valves operate as switches which turn on and conduct current when fired on receiving a gate pulse and are forward biased.

The characteristic AC side current harmonics generated by 6-pulse converters are 6n±1, Characteristic DC side voltage harmonics generated by a 6-pulse converter are of the order 6n±1.

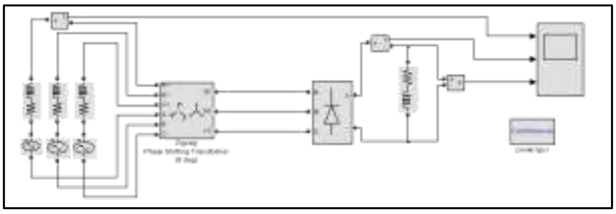


Fig. 3: Uncontrolled Six-Pulse Converter

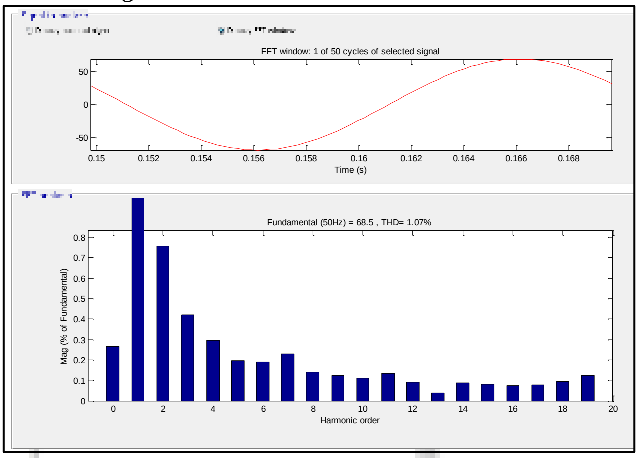


Fig. 4: THD for input current

B. *Twelve Pulse Converter*

Twelve-pulse converter is a series connection of two fully controlled six pulse converter bridges and requires two 3-phase systems which are spaced apart from each other by 30 electrical degrees. The phase difference effected to cancel out the 6-pulse harmonics on the AC and DC side.

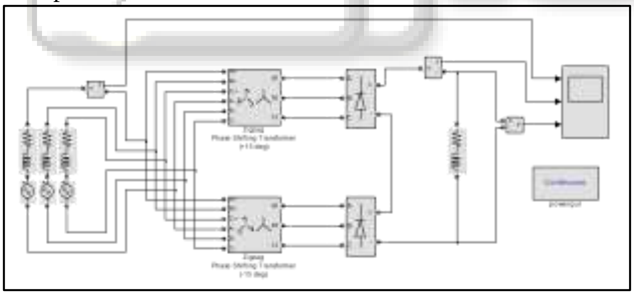


Fig. 5: Uncontrolled twelve pulse converter

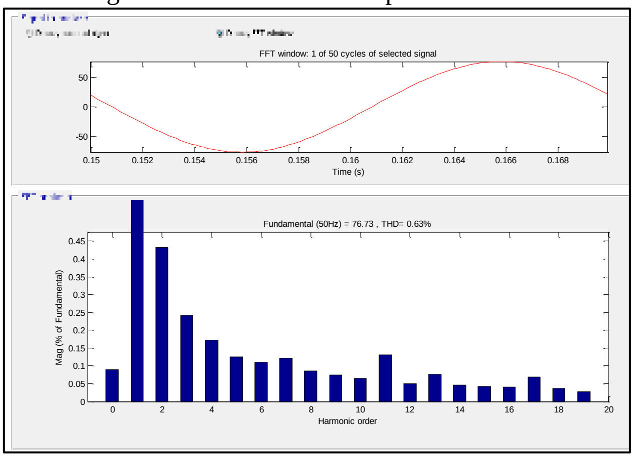


Fig. 6: THD for input current

C. *Eighteen Pulse Converter*

In this 18-pulse topology, the magnetic circuit involved is same as that of a 6-pulse converter. Therefore this topology is comparatively a preferred one. The simulated results are in close agreement with any result obtained from an 18 pulse converters. A phase shift of 20^0 has been provided between all three phase shift transformers with star connected secondary.

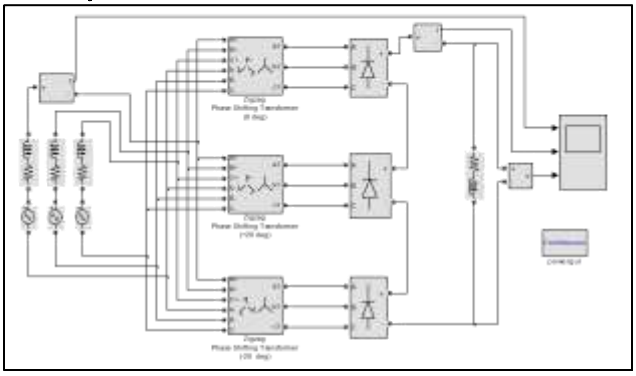


Fig. 7: Uncontrolled eighteen pulse converter

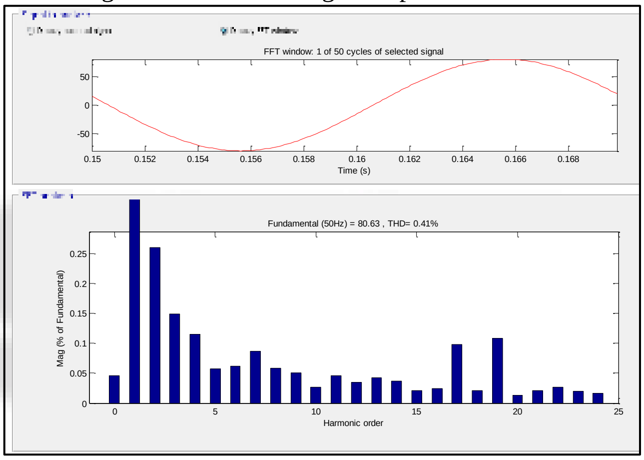


Fig. 8: THD for input current

D. *Twenty-Four Pulse Converter*

The connection for 24-pulse converter and the corresponding connections are shown in fig. 9. Four six pulse converters phase shifted by 15 degrees from each other, can provide twenty four pulse rectification, obviously with much lower harmonics on AC and DC side. Its AC output voltage would have 24n±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 phase shift.

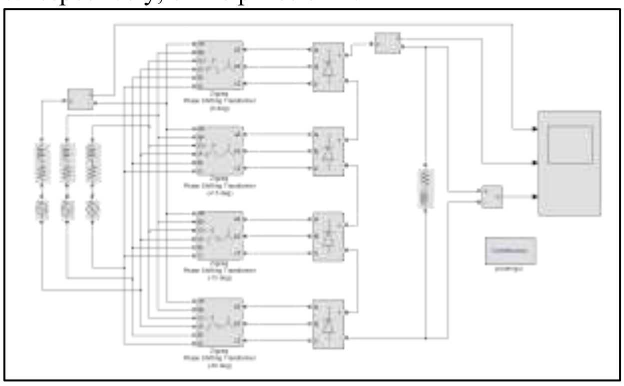


Fig. 9: Uncontrolled twenty four pulse converter

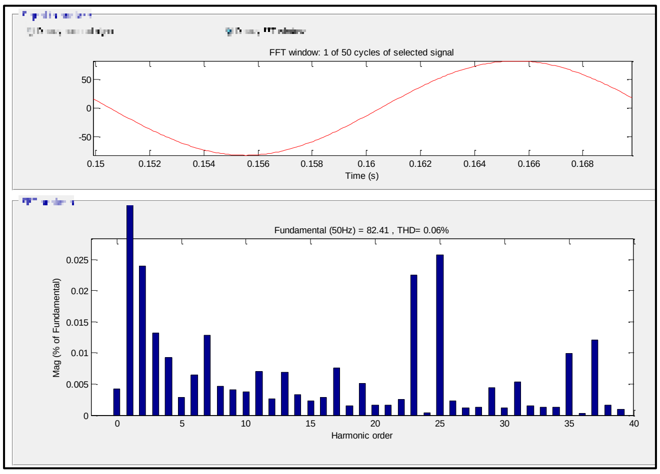


Fig. 10: THD for input current

E. Thirty-Pulse Converter

The connection for 30-pulse converter and the corresponding connections are shown in fig. 11, six pulse converters phase shifted by 12 degrees from each other, can provide thirty-pulse conversion, and obviously with much lower harmonics on AC and DC side. Its AC output voltage would have 30n±1 order harmonics i.e., 29^{th}, 31^{st}, 59^{th}, 61^{st} harmonics with magnitudes of $1/29^{th}$, $1/31^{st}$, $1/59^{th}$, $1/61^{st}$,…respectively, of the phase shift.

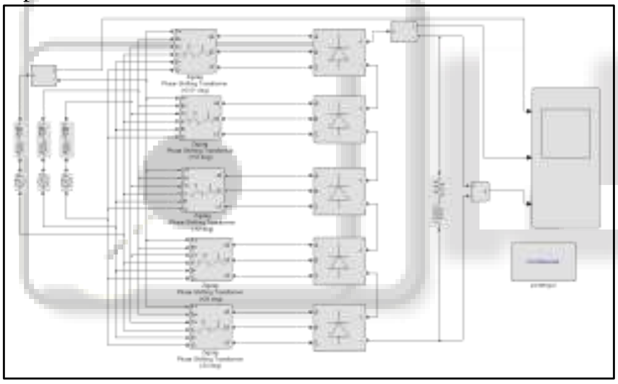


Fig. 11: Uncontrolled thirty pulse converter

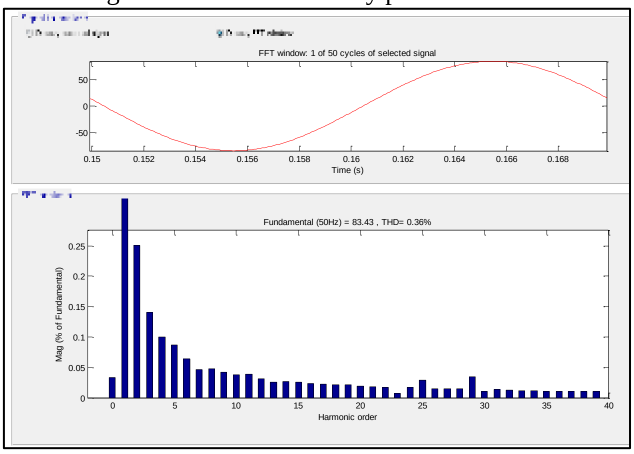


Fig. 12: THD for input current

F. Thirty-Six Pulse Converter

The connection for 36-pulse converter and the corresponding connections are shown in fig. 13. Six six-pulse converters phase shifted by 10^0 from each other, can provide thirty-six pulse conversion, and obviously with much lower harmonics on AC and DC side. Its AC output voltage would have 30n±1order harmonics.

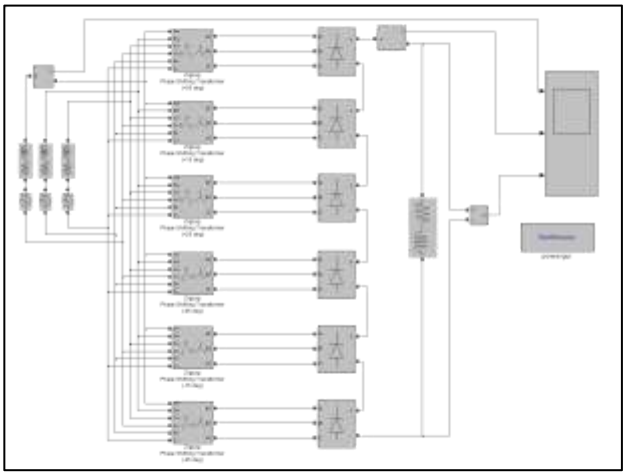


Fig. 13: Uncontrolled Thirty-Six Pulse Converter

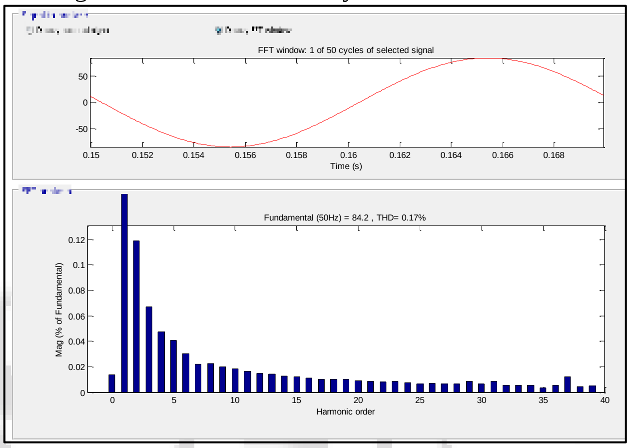


Fig. 14: THD for input current

G. Forty-Eight Pulse Converter

For high power FACTS controllers, from the point of view of the AC systems even a twenty-four, thirty or thirty-six pulse converter without AC filters could have voltage harmonics, which are higher than the acceptable level. The alternative is to go for 48 pulse operation with eight six-pulse converters phase shifted from each other by 7.5 degrees. All 8 transformer primaries are to be connected in series.

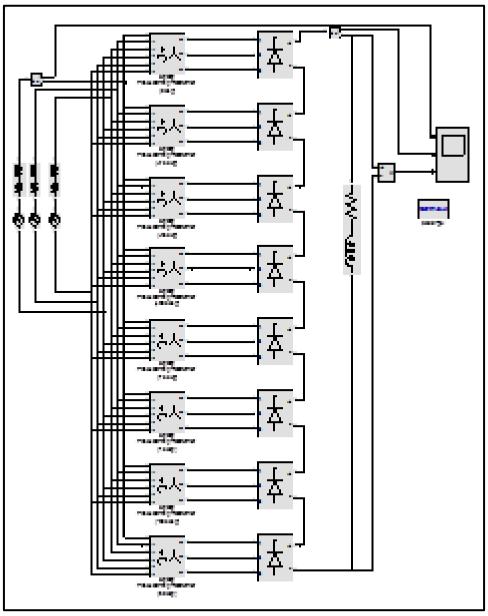


Fig. 15: Uncontrolled Forty-Eight Pulse Converter

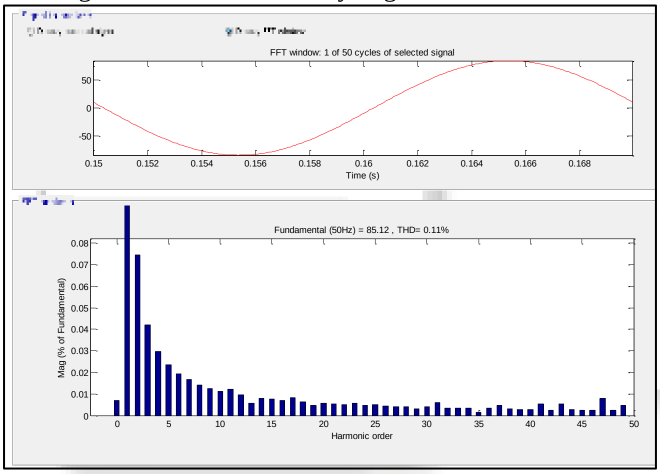


Fig. 16: THD for input current

V. 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.

A. Six-Pulse Converter

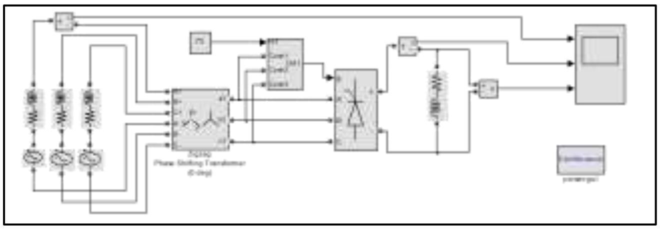


Fig. 17: Controlled six-pulse Converter

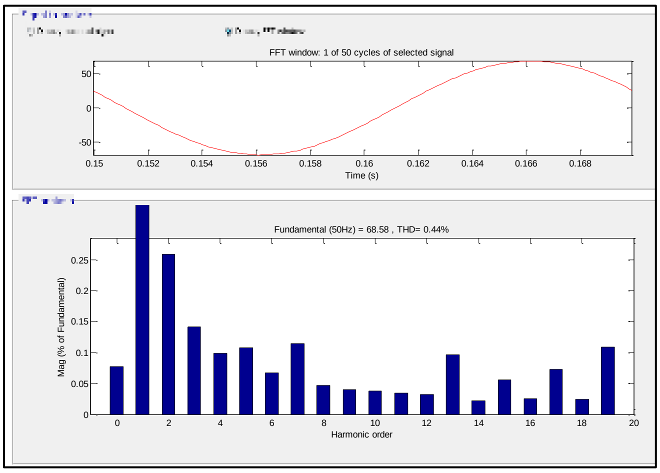


Fig. 18: THD for input current

B. Twelve Pulse Converter

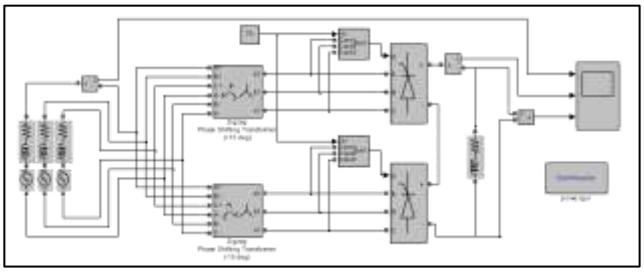


Fig. 19: Controlled Twelve Pulse Converter

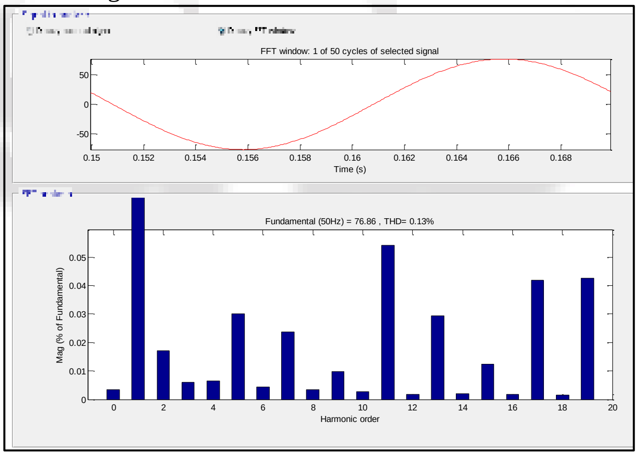


Fig. 20: THD for input current

C. Eighteen-Pulse Converter

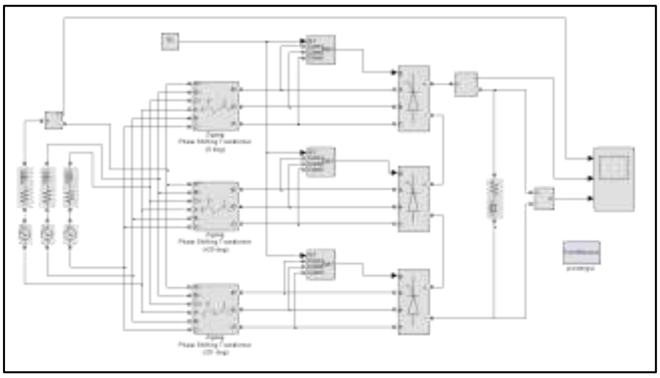


Fig. 21: Controlled eighteen pulse converter

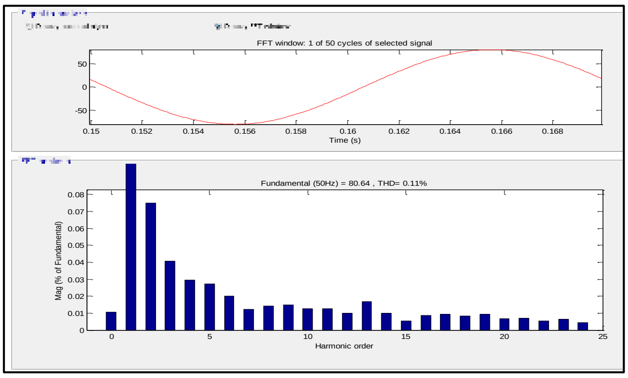


Fig. 22: THD for input current

D. Twenty-Four Pulse Converter

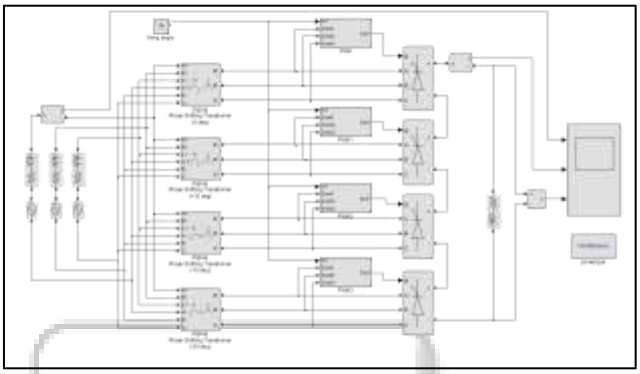


Fig. 23. Controlled twenty four pulse converter

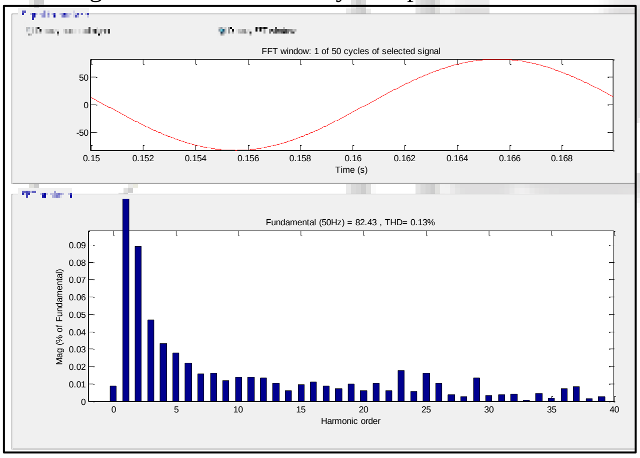


Fig. 24: THD for input current

E. Thirty Pulse Converter

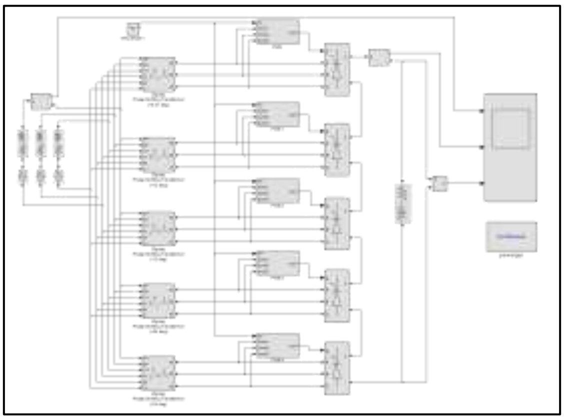


Fig. 25. Controlled Thirty Pulse Converter

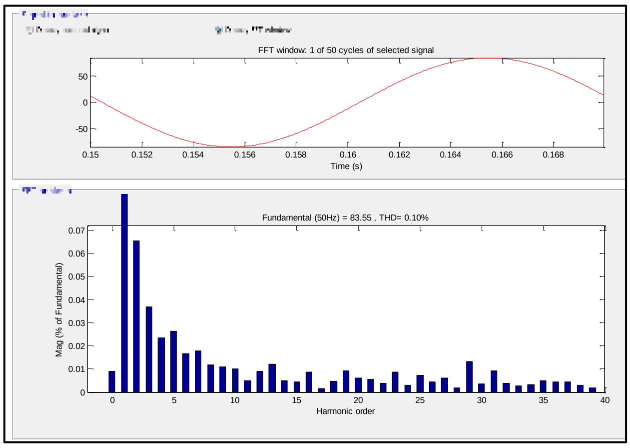


Fig. 26: THD for input current

F. Thirty-Six Pulse Converter

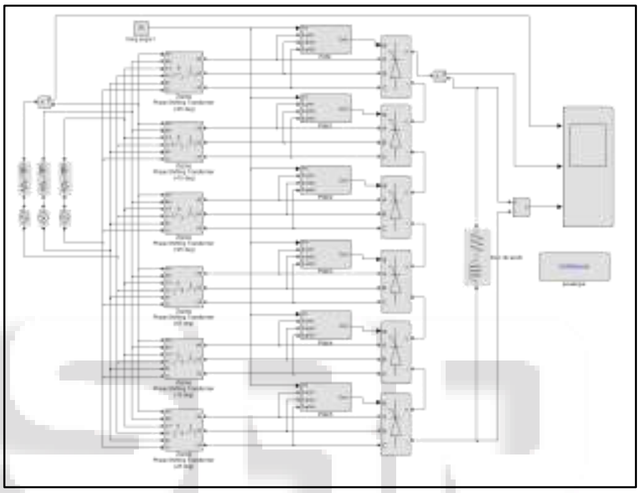


Fig. 27. Controlled Thirty-Six Pulse Converter

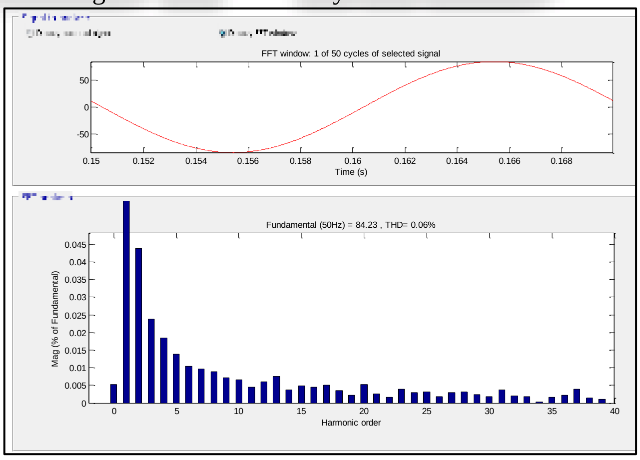


Fig. 28. THD for input current

G. Forty-Eight Pulse Converter

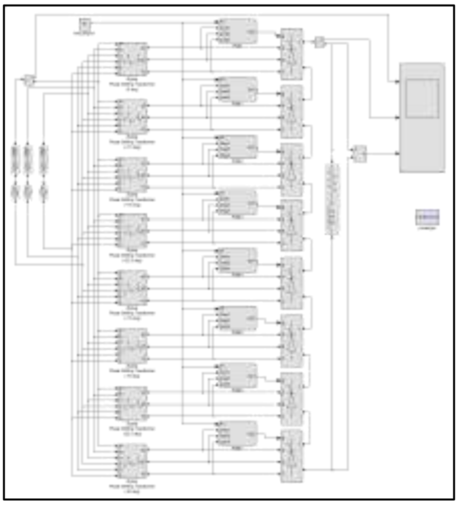


Fig. 29: Controlled Forty-Eight Pulse Converter

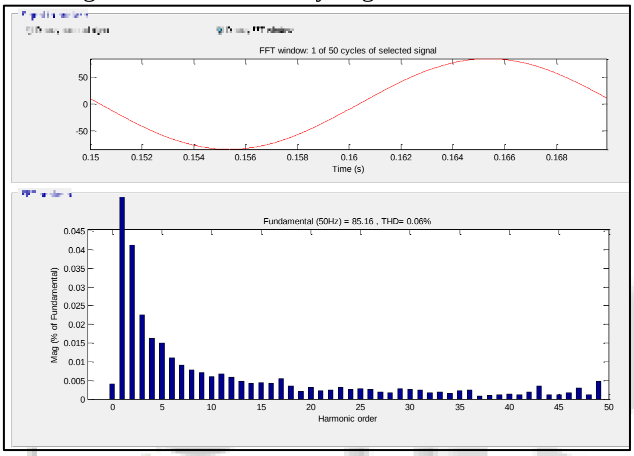


Fig. 30: THD for input current

VI. SIMULATION RESULTS OBTAINED FOR MULTI-PULSE CONVERTERS

A. Uncontrolled Multi-Pulse Converters

1) Analysis of Supply Current THD

No. of Pulses	R Load	RL Load	RC Load
06	0.78	1.07	1.21
12	0.51	0.63	0.65
18	0.37	0.41	0.45
24	0.24	0.06	0.38
30	0.20	0.36	0.36
36	0.20	0.17	0.18
48	0.14	0.11	0.28

Table 1: Total Harmonic Distortion Observed on Simulation

2) Analysis of DC Voltage Ripple Content

No. of Pulses	R Load	RL Load	RC Load
06	4.625	4.352	4.385
12	1.412	0.9479	0.9399
18	1.066	0.5821	0.5848
24	0.7492	0.0588	0.3256
30	0.4954	0.313	0.3328
36	0.4477	0.2739	0.2198
48	0.5320	0.2988	0.3478

Table 2: % Ripple Content Observed on Simulation

3) Analysis of DC Voltage Form Factor

No. of Pulses	R Load	RL Load	RC Load
06	1.001	1.001	1.001
12	1	1	1
18	1	1	1
24	1	1	1
30	1	1	1
36	1	1	1
48	1	1	1

Table 3: Form Factor Observed on Simulation

B. Controlled Multi-Pulse Converters

1) Analysis of Supply Current THD

No. of Pulses	R Load	RL Load	RC Load
06	0.45	0.44	7.64
12	0.13	0.13	0.14
18	0.11	0.11	0.23
24	0.11	0.13	0.19
30	0.09	0.10	0.11
36	0.03	0.06	0.09
48	0.09	0.06	0.02

Table 4: Total Harmonic Distortion Observed on Simulation

2) Analysis of Ripple Content

No. of Pulses	R Load	RL Load	RC Load
06	4.559	12.13	78.08
12	6.145	35.44	6.412
18	4.503	4.499	4.495
24	3.356	3.334	3.342
30	2.550	2.56	2.497
36	2.158	2.127	2.078
48	1.571	1.606	1.625

Table 5: % Ripple Content Observed on Simulation

3) Analysis of Form Factor

No. of Pulses	R Load	RL Load	RC Load
06	1.012	1.007	1.263
12	1.002	1.002	1.002
18	1.001	1.001	1.001
24	1.001	1.001	1.001
30	1	1	1
36	1	1	1
48	1	1	1

Table 6: Form Factor Observed on Simulation

VII. CONCLUSION

A. Simulation

The various isolated multi-pulse configurations were simulated using the software MATLAB / SIMULINK[5] and the results have been presented in this chapter in Table 1 to Table 6. The effect of load variation on different multi-pulse converters reveals that with RL load because of inductance there is smoothing effect on current, therefore current THD decreases. The effect is similar for different multi-pulse converters, i.e. it increases current discontinuity and hence affecting the harmonic spectrum adversely.

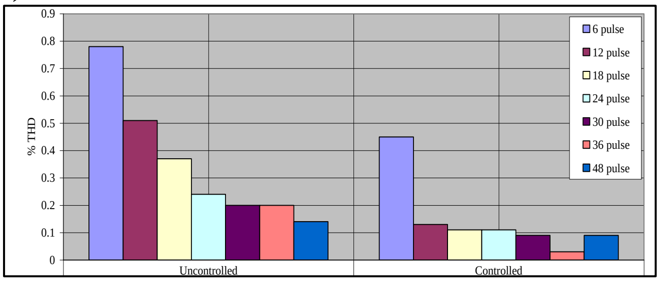
B. Performance Analysis And Comparison

All the data obtained after simulation of aforesaid models using MATLAB/SIMULINK has been collected here so as to ease the comparison of factors accounted for i.e. THD, Ripple

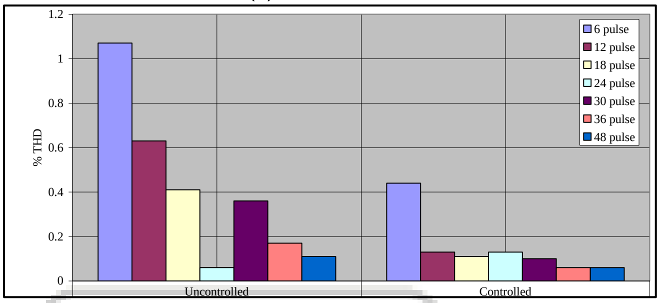
Content and Form Factor between Uncontrolled & Controlled Multi-pulse converters.

All the results obtained have been collected from Tables 5.1 to 5.6 and categorised on the basis of Load provided so as to ease the comparison.

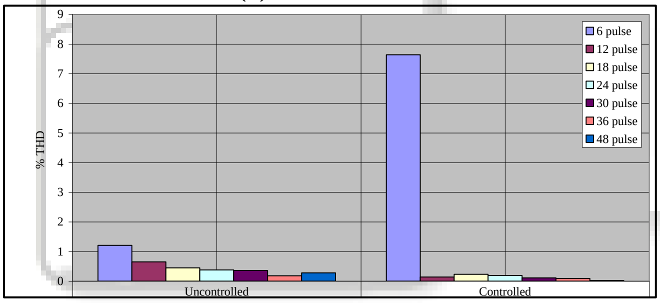
1) Total Harmonic Distortion



(a) For R Load



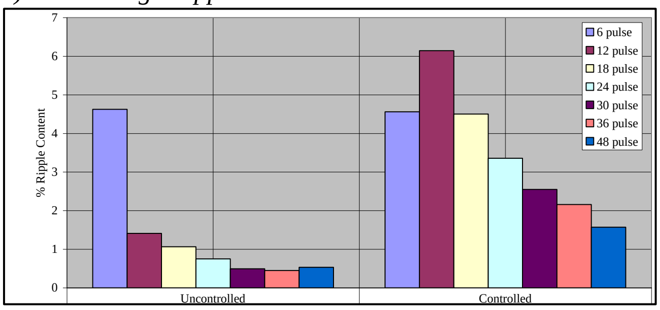
(b) For RL Load



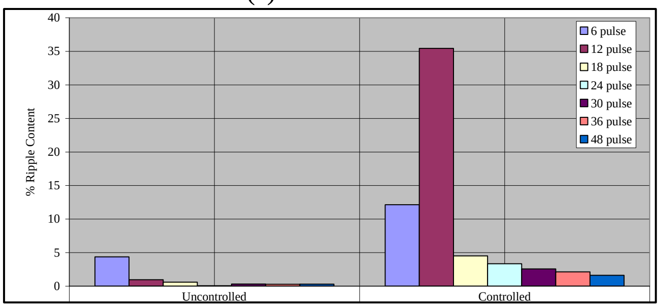
(c) For RC Load

Fig. 31: THD Comparison: *(a) – (c)*

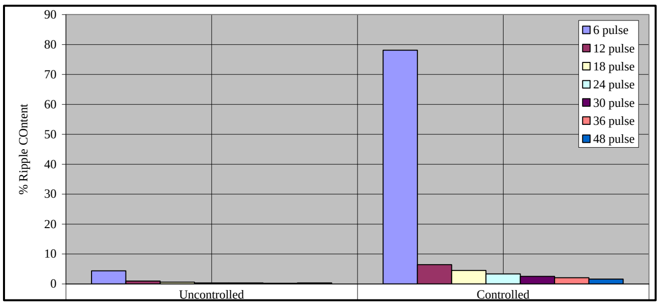
2) Percentage Ripple Content



(a) For R Load



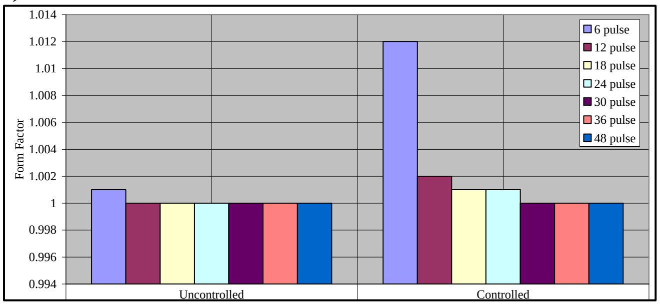
(b) For RL Load



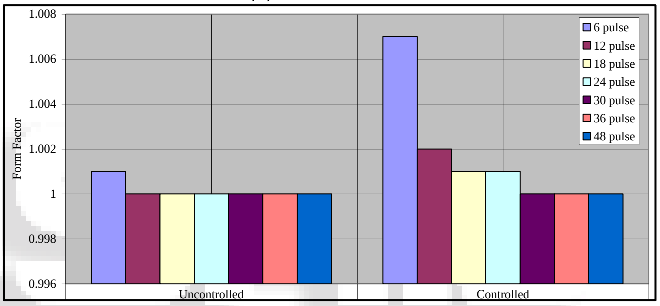
(c) For RC Load

Fig. 32. %Ripple Content Comparison: *(a) – (c)*

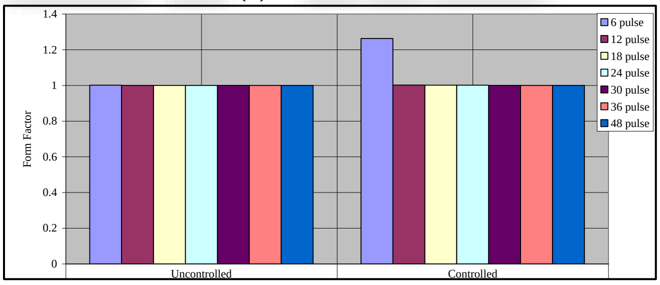
3) Form Factor



(a) For R Load



(b) For RL Load



(c) For RC Load

Fig. 33. Form Factor Comparison: *(a) – (c)*

VIII. RESULT OF SIMULATION

The objective of the present work is to investigate the performance of controlled and uncontrolled multi-pulse converters. These converters are studied in terms of harmonic spectrum of AC supply current, Total Harmonic Distortion, Ripple Content & form factor in the AC supply. It is concluded therefore that in general with increase in number of pulses in multi-pulse case the performance parameters of these converters have remarkably improved.

The THD for controlled converters has reduced than for the consecutive uncontrolled converters.

For RC Load as implecated, the ripple content has significantly increased in comparison to R and RL Load.

IX. FUTURE SCOPE

A back-to-back asynchronous tie comprised of VSC converters employing PWM may well represent the ultimate HVDC system. Besides controlling the through power flow, it can supply reactive power and provide independent dynamic voltage control at its two terminals. The two converters can be paralleled to double the reactive power capability supplied to one side or the other. The back-to-back converters can be used for black start or to supply a passive load. Higher voltage designs can be used with transmission lines or cables to form point-to-point or multi-terminal transmission links. More sophisticated controls can be used to provide additional network benefits. With the Eagle Pass project, CSW has realized the system advantages of deploying a VSC based back-to-back asynchronous Tie with standby dynamic voltage control during network contingencies. The controlled power transfer capability allows the exchange of power between the two networks while the voltage control stabilizes the voltage following line outages especially during peak load periods.

The future scope of work could be the simulation of 6, 12, 18, 24, 30, 36, 48 multi pulse converter topologies in closed loop.

With this technique, this work can be further extended to:

1) Number of pulses can be increased. Even higher pulse converters can be used for high voltage and high power applications such as HVDC conversion.
2) Closed Loop Multi-pulse conversion can be worked out for enhanced controlling and efficiency.
3) Other method of increasing the pulses can be used in place of phase shifting transformers as to derive multiphase supply from three phase AC mains using different combinations of transformer windings such as star, delta, zigzag, fork, polygon, etc.

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