Power Quality Improvement by Input Current Harmonic Reduction Using Three-Phase Multi-Pulse AC-DC Converter

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***Abstract*—This is a well-known fact that during a transformer-rectifier combination undesirable harmonic line currents may be generated. The rectification of alternating current power to direct current power itself may produce undesirable current harmonics. The non-linear loads cause the severe current harmonics that can not be tolerated. These harmonic currents can cause either a shutdown of the device or the unacceptable powering of the devices. The non-isolated multi-pulse converters and the Multi-pulse converters in general can be applied to achieve the clean power which is of major priority in higher power rating applications. Generally, by increasing the number of pulses in a multi-pulse converter THD (total harmonic distortion) can be reduced up to the allowable limits.**

Thepresentwork istoanalyses the differentmulti-pulse AC toDC (18-pulse, 24-pulse, 36-pulse, and 48-pules) converters insolvingthe harmonic problem in athree-phase converter system. The effect of increasing the number of pulses on the performance of ac-dc converters is analyzed. THD is the major factor considered for the performance comparison of various converters.

Keywords-Power quality, harmonics, total harmonic distortion, ac-dc converter.

I. INTRODUCTION

Power electronic devices are non-linear loads that create harmonic distortion and can be susceptible to voltage dips if no adequately protected. The most common economically damaging power quality problem encountered in volves 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 drives (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), inprocess 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, result ant voltage distortion and poor power factor at input ac main sand slowly varying rippled dc output at load end, low efficiency, and large size of ac and dc filters.

This paper is divided into five Sections. First section is Introduction (Section I). Other sections are review on multi-pulse converter (Section II), converter configuration (Section III), Simulation and results (Section IV) and the last section is the conclusion of the analysis (Section V).

II. REVIEW ON MULTI-PULSE CONVERTER

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 auto transformer arrangement. Choi [2] in this paper has presented new auto transformer 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] have proposed a new isolated high power factor 12KW power supply basedon18-pulse transformer arrangement. The topology used in volves a simple control strategy. Simulations and experimental results are given in paper. S.Kim Etal [4] has given an analysis and design of a passive and novel inter connection of a star/delta transformer approach to improve power factor and reduce harmonics generated by a three phase diode rectifier. Chen Etal [5]has proposed anew passive28-step current shaper for three phase rectification with a phase shifting transformer on the ac side, per phase input current is shaped into sinusoidal waveform.

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 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.

Multi-pulse systems result in two major accomplishments,

1. Reduction of input line current harmonics.
2. Reduction of output voltage e ripple.

Reduction of ac input line current harmonics is important as regards the impact the converter has on the power system. Multi-pulse methods are characterized by the use of multiple converters or multiple semiconductor devices with a common load. Phase shifting transformers are an essential ingredient and provide the mechanism for cancellation of harmonic current pairs, e.g. the 5thand 7thharmonics or the 11th and 13thsoon. Thus for harmonic current reduction them ulti- pulse converters are fed from phase shifting transformers. The phase shift has to be appropriate.

III. CONVERTER CONFIGURATION

A. 18-Pulse AC-DC Converter

Fig. 1 shows the general configuration of 18-pulse ac-dc converter. The rectifier has three units identical of 6-pulse diode rectifiers fed by a phase shifting transformer. The sign "Z" enclosed by a circle represents a three-phase zigzag-connected winding, which provides a required phase displacement between the primary and secondary line-to-line voltages.

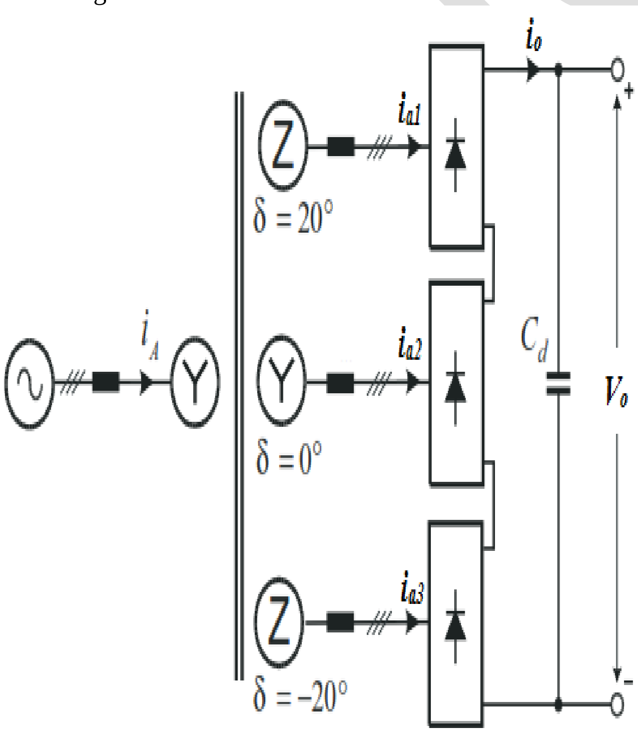

Fig. 1: 18-pulse ac-dc converter configuration

18-pulse ac-dc converter can eliminate four dominant harmonics the 5th, 7th, 11th and 13th. This is achieved by using a phase-shifting transformer with phase displacement of 20° between any two adjacent secondary windings. The typical values of δ are 20°, 0° and -20° for the first, second and third secondary windings, respectively. The other possible arrangement for this is 0°, 20° and 40° respectively.

B. 24-Pulse AC-DC Converter

Fig. 2 shows the general configuration of 24-pulse ac-dc converter. The rectifier has four identical units of 6-pulse diode rectifiers fed by a phase shifting transformer.24-pulse ac-dc converter can eliminate six dominant harmonics the 5th, 7th, 11th, 13th, 17th, and 19th[6]. In 24-pulse ac-dc converter there must be a phase displacement of 15° between any two adjacent secondary winding voltages. For this phase-shifting transformer is employed with phase displacement of 15°.

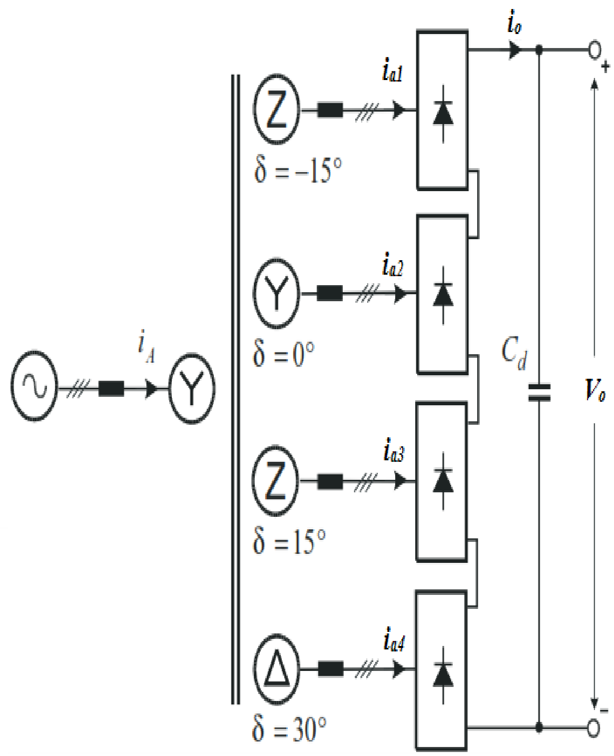

Fig. 2: 24-pulse ac-dc converter configuration

The typical values of δ are -15°, 0°, 15° and 30° for the first, second, third and fourth secondary windings, respectively. The other possible arrangement for this is 0°, 15°, 30° and 45° respectively.

C. 36-Pulse AC-DC Converter

Fig. 3 shows the general configuration of 36-pulse ac-dc converter. It has six identical units of 6-pulse diode rectifiers fed by a phase shifting transformer. In 36-pulse ac-dc converter the required phase displacement between two adjacent secondary winding voltages is 10° and the typical values of δ are -25°, -15°,-5°, 5°, 15° and 25° [6].

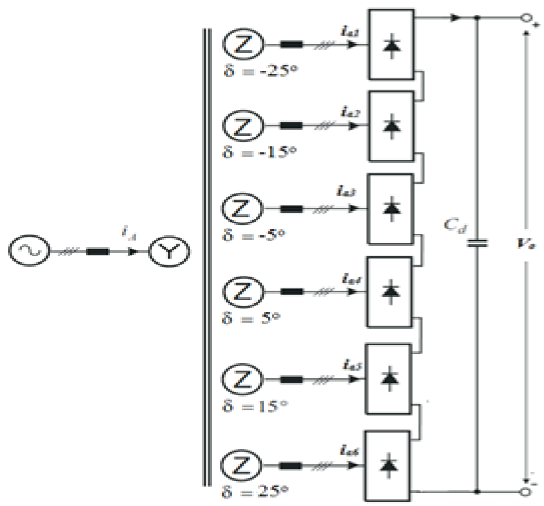

Fig. 3: 36-pulse ac-dc converter configuration

D. 48-Pulse AC-DC Converter

Fig. 4 shows the general configuration of 48-pulse ac-dc converter. The rectifier has eight identical units of 6-pulse diode rectifiers fed by a phase shifting transformer.

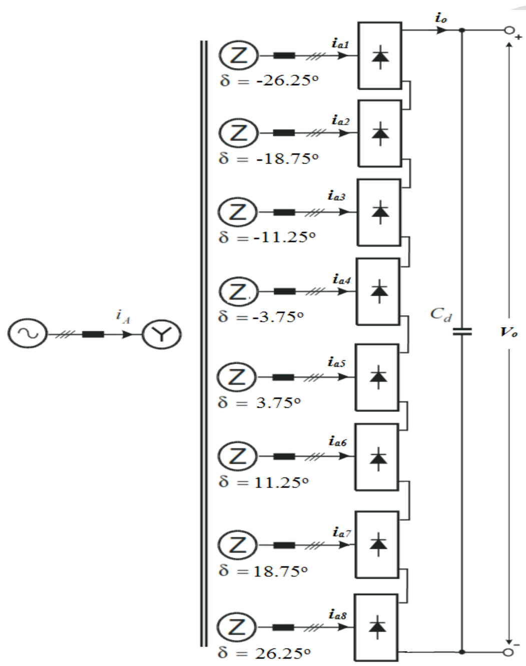

Fig. 4: 48-pulse ac-dc converter configuration

For 48-pulse ac-dc converter the required phase displacement between two adjacent secondary winding voltages is 7.5° and the typical values of δ are -26.25°, -18.75°, -11.25°, -3.75°, 3.75°, 11.25°, 18.75° and 26.25°.

IV. MATLAB SIMULATIONAND RESULTS

A. 18-Pulse AC-DCConverter Simulation

The MATLAB Simulink model of an 18-pulse uncontrolled rectifier is shown in Fig. 5. For 18-pulse controlled rectifier all the diodes in bridge rectifiers are replaced by thyristors and a gate pulse generator is added as shown in Fig. 7. THD in the input current is calculated and shown in Fig. 6.

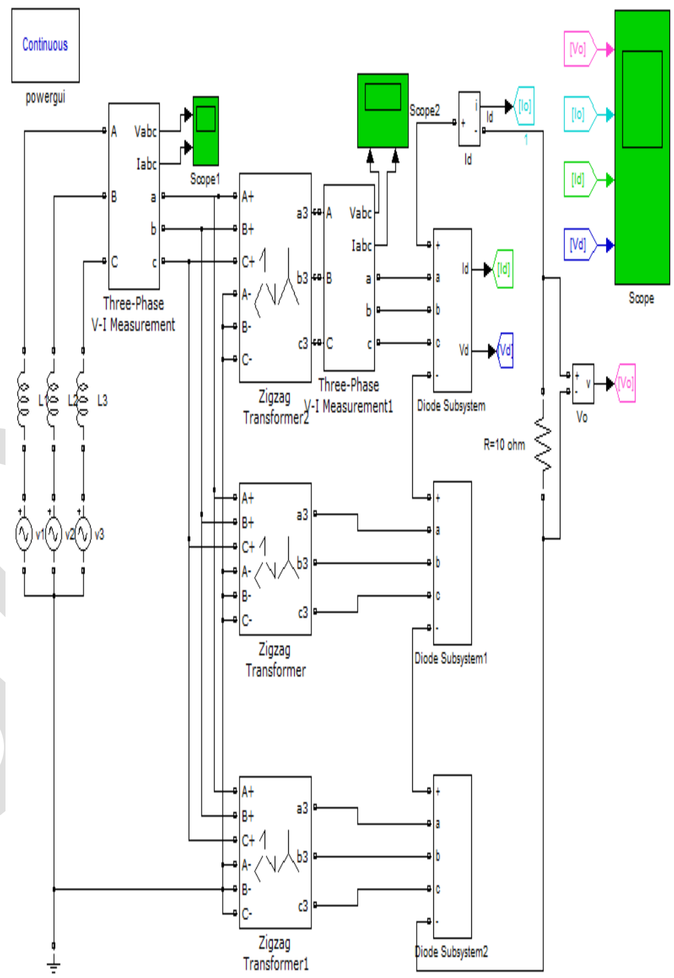

Fig. 5: Three-phase uncontrolled 18-pulse ac-dc converter

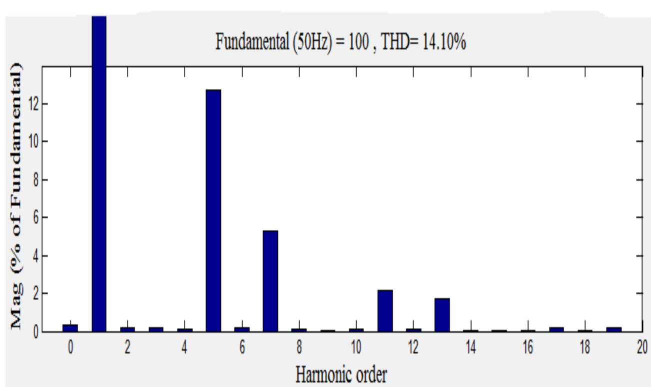

Fig. 6: Input current THD of uncontrolled 18-pulseac-dc converter

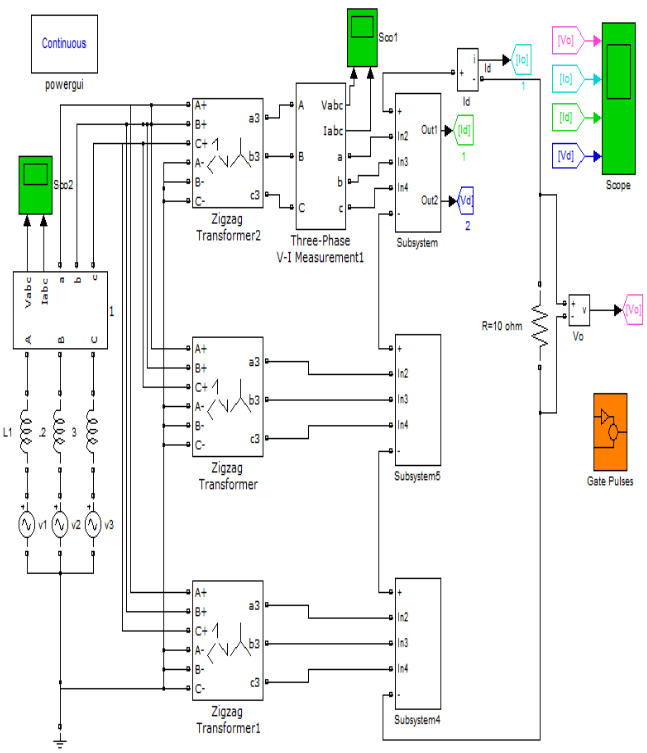

Fig. 7: Three-phase controlled 18-pulse ac-dc converter

Fig. 8 shows the FFT analysis of one of the three-phase input currents to the 18-pulse controlled rectifier. The calculated THD to the input current of 18-pulse controlled rectifier is 13.86%.

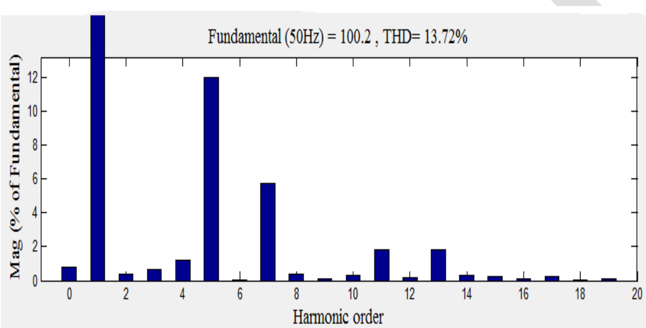

Fig. 8: Input current THD of controlled 18-pulseac-dc converter

B. 24-Pulse AC-DCConverter Simulation

Addition of one more identical rectifier circuit in series with the 18-pulse converter with a phase shift of 15^o between two adjacent secondary winding voltages, 24-pulse uncontrolled rectifier is obtained. Replacement of those diode rectifiers with the thyristor converters will become 24-pulse controlled ac-dc converter.Fig. 9 and Fig. 10showthe FFT analysis of one of the three-phase input currents to the 24-pulse uncontrolled and controlled rectifierrespectively. The calculated THD is 12.82% and 10.96% respectively.

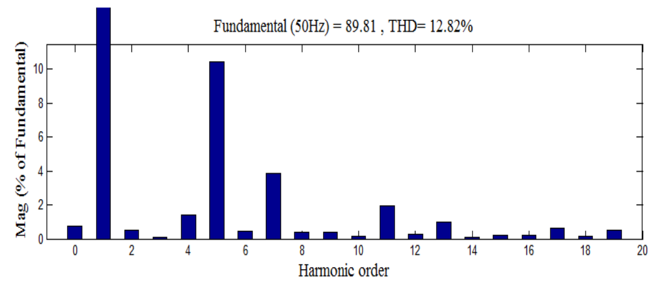

Fig. 9: Input current THD of uncontrolled 24-pulseac-dc converter

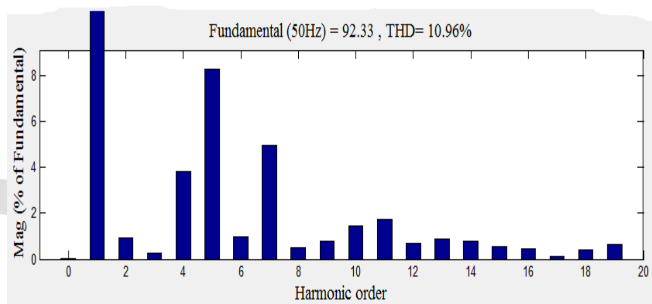

Fig. 10: Input current THD of controlled 24-pulseac-dc converter

C. 36-Pulse AC-DCConverter Simulation

As explained in Section III (C) 36-pulse ac-dc converter have six identical rectifier units connected in series and the phase difference between two adjacent secondary winding voltages is 10^o.

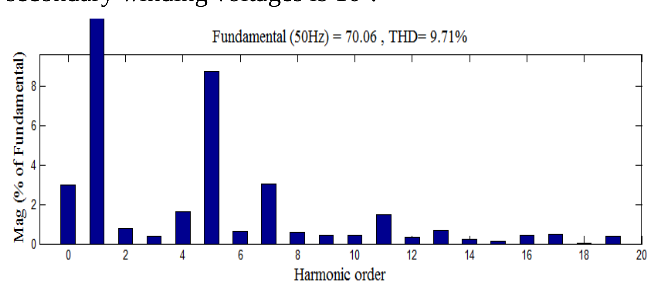

Fig. 11: Input current THD of uncontrolled 36-pulseac-dc converter

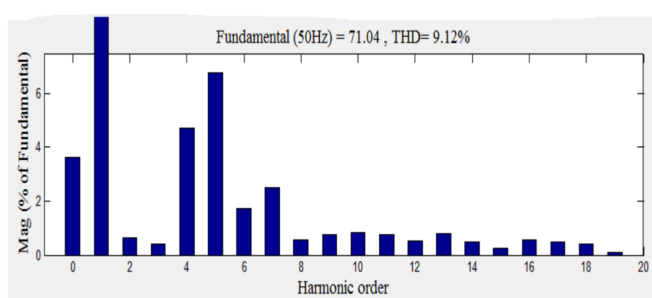

Fig. 12: Input current THD of controlled 36-pulseac-dc converter

D. 48-Pulse AC-DCConverter Simulation

Eight identical rectifiers connected in series with the phase difference of 3.5^o between two adjacent secondary winding voltages, operate as a 48-pulse ac-dc converter. The MATLAB Simulink model for 48-pulse uncontrolled rectifier is shown in Fig. 13. If all the diode rectifiers from Fig. 13 are replaced by thyristor bridges, it will become 48-pulse controlled ac-dc converter as shown in Fig. 15 below. Fig. 14 and Fig. 16 show the THD calculated for the 48-pilse uncontrolled and controlled ac-dc converter respectively.

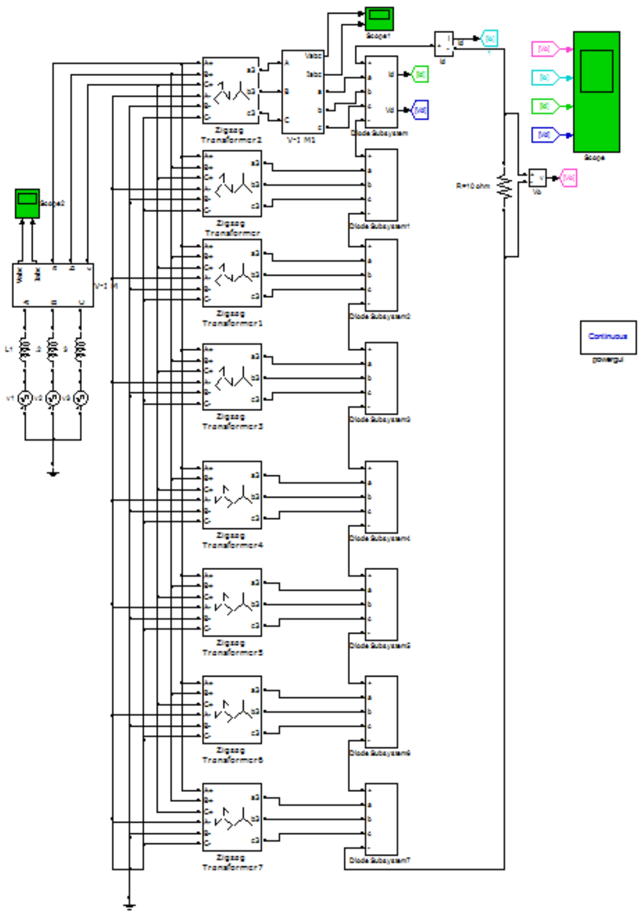

Fig. 13: Three-phase uncontrolled 48-pulse ac-dc converter

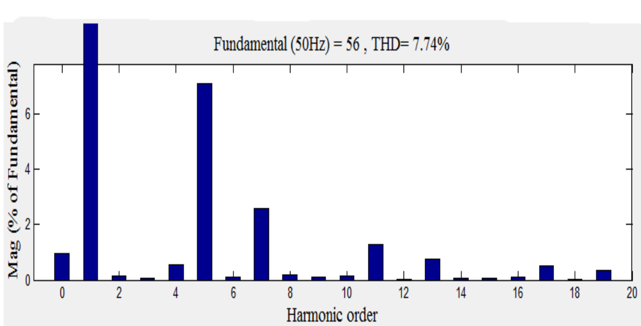

Fig. 14: Input current THD of uncontrolled 48-pulseac-dc converter

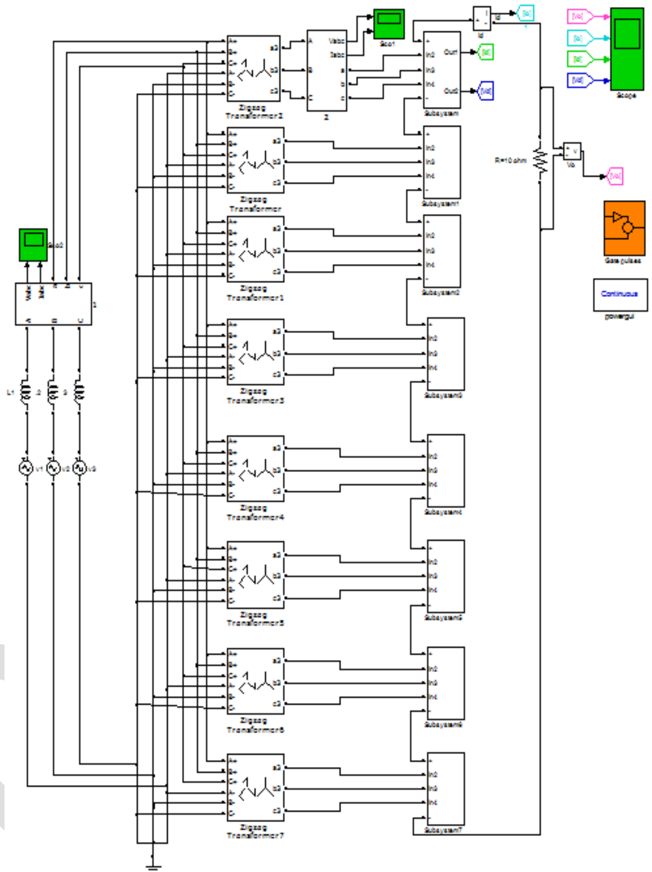

Fig. 15: Three-phase controlled 48-pulse ac-dc converter

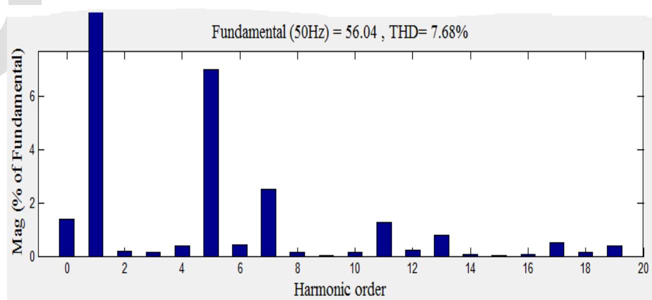

Fig. 16: Input current THD of controlled 48-pulseac-dc converter

V. CONCLUSION

From the above simulations and their results it can be concluded that with the increase in number of pulses of converter improves the power quality by reducing the input current harmonics from the ac mains. Hence pulse multiplication technique can play an important role in power quality improvement in various applications such as power distribution networks, HVDC transmission systems, critical industrial and commercial loads etc. Table 1 shows the positive impact of increase in number of pulses on the input current harmonics.

Table 1: Comparison of input current THD

Sr. No.	Converter	Uncontrolled	Controlled
1	18-Pulse	14.03%	13.91%
2	24-Pulse	12.33%	11.46%
3	36-Pulse	9.30%	8.79%
4	48-Pulse	5.97%	7.40%

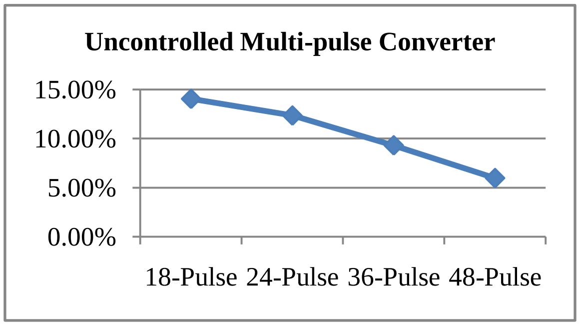

Fig. 17: Reduction in input current THD with increase in number of pulses in uncontrolled ac-dc converters

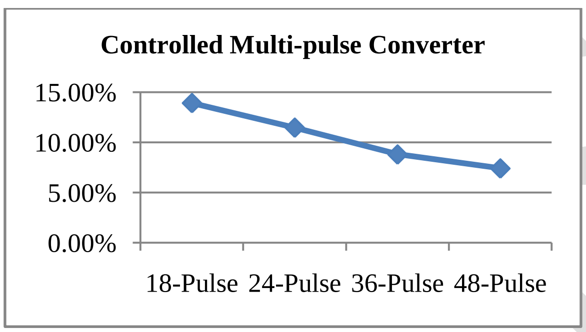

Fig. 18: Reduction in input current THD with increase in number of pulses in controlled ac-dc converters

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