International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 5, Number 3 (2012), pp. 255-263

http://www.irphouse.com

Power Quality Improvement using a 28-pulse AC-DC Converter for SMPS

Suresh K., *R. Hanuma Naik
and Veera Bramhananda Reddy M.

Assistant Professor,
Rajeev Gandhi Memorial College of Engineering and Technology,
Nandyal, A.P., India
*E-mail: Karasani.suresh@gmail.com, *rhnaik.1717@gmail.com*

Abstract

In this paper a novel auto connected transformer based 28-pulse ac-dc converter fed SMPS is designed to improve the power quality at the point of common coupling. It consists of two series connected 14-pulse ac-dc uncontrolled converters fed by seven phase shifted ac voltages. The behaviour of the converter is studied in MATLAB based simulation under various load conditions. It has been found that the % input ac mains current THD is less than 5% in the complete range of varying loads, with a power factor close to unity which meets the requirements of IEEE-519 standard. Thus, our proposed topology resulted in much reduction in % input mains current THD with enhanced power factor compared to conventional multi pulse ac-dc converter.

Index Terms: IGBT, Bridge rectifier, Pulse converter, auto connected transformer, THD, power quality, power factor, pulse transformer. SMPS.

Introduction

Telecommunication power supply system requires stiffly regulated output voltages with much reduced % input ac mains current THD at the near unity power factor. In the conventional system AC supply voltage is connected to a DC-link voltage by a diode rectifier with output filter capacitor. A high frequency DC-DC converter, with regulated output voltage, is then connected in series with the Dc-link voltage. But it has high low frequency current harmonics which leads to distortion of AC supply voltage. Later on, the DC-DC converter is fed from six-pulse three phase ac-dc uncontrolled converter at the front-end that are rugged and reliable; however, the line current drawn from the utility by these converters presents high total harmonic distortion (THD) and poor power factor. These harmonics can be reduced by using multipulse ac-dc converters [1]. International power quality standards such as IEEE-519 were proposed to maintain THD and the power factor at acceptable levels [2].

Many researchers have been focusing to improve the power quality of the converters to replace the conventional ac-dc converters by improved power quality ac-dc converters that draw a nearly sinusoidal input ac mains current with unity power factor. Multipulse ac-dc converters with phase shifting technique [3] are one of the popular approaches to reduce the harmonics in medium and high power rectifier type of loads. This rectification approach has gained popularity due to its robust, rugged nature, reliability and simplicity in control.

Different multipulse ac-dc converters configurations are reported in the literature [4-5] to reduce the line current harmonics. Multipulse converters have been used as an improved power quality utility interface in a variety of publications such as telecommunication power supplies, electric aircraft applications and variable frequency induction motor drives [6]. Hammond et al [7] has proposed an auto connected transformer configuration which produces multiphase output phase voltages which is not a multiple of three. It is observed that an ac-dc converter with number of phases which is not multiple of three is effective in reducing the line current harmonics.

This paper proposes a new 28-pulse ac-dc converter which is a combination of both multiphase and phase staggering technique for medium capacity SMPS. The proposed auto connected transformer based ac-dc converter is based on multiphase technique that produces seven-phases from three-phase input supply. The advantages of the present converter approach are that it is inexpensive, reliable and energy-efficient. Moreover, the THD of ac mains current is low and the power factor is well improved. Fig.1 presents a schematic diagram of a medium capacity SMPS using a full-bridge converter that has a 6-pulse converter at the front end. For a normal 3-phase diode bridge rectifier, the power quality indices at the ac mains do not conform to IEEE 519 standard.

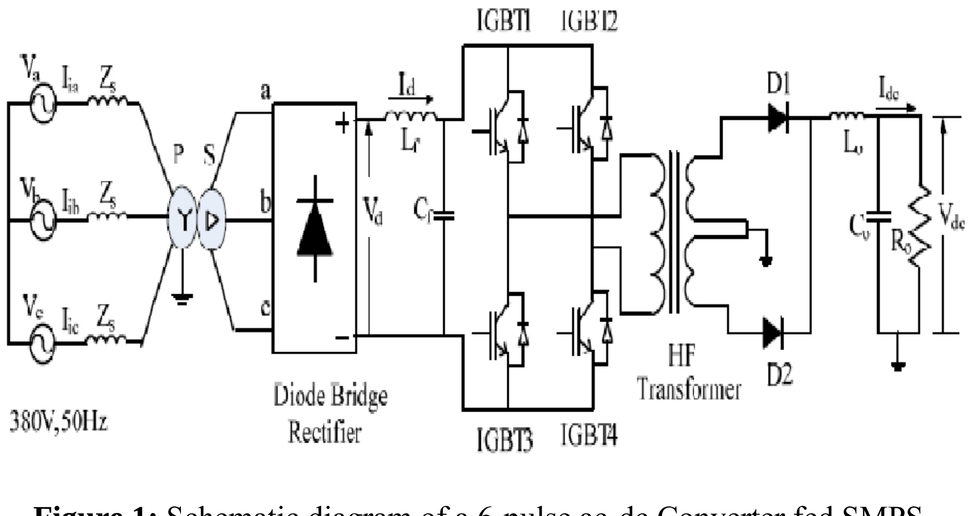


Figure 1: Schematic diagram of a 6-pulse ac-dc Converter fed SMPS.

In this paper, an auto connected transformer based 28-pulse ac-dc converter is presented to improve the power quality at the utility interface to achieve a power factor close to unity. Design methodology of the proposed auto connected transformer based 28-pulse ac-dc converter is a included in the following sections. The operation of the ac-dc converter at constant dc load current is investigated.

Structure of the Proposed System

Fig. 2 shows the overall system configuration. It is shown that the proposed auto connected transformer based 28-pulse ac-dc converter is feeding a 12kW SMPS load with the isolated full-bridge dc-dc converters. The proposed auto connected transformer secondary generates two sets of seven-phase voltage for the two seven-phase diode bridge rectifiers. The dc side of each seven-phase diode bridge rectifiers is connected to the isolated full-bridge dc-dc converters with a dc-link LC filter in between them. A dc-link LC filter (Lf, Cf) is placed on each of the dc-links to filter out the harmonics which are multiples of 2nd order. The electrical isolation between the input-output is provided by the high frequency transformer. Each transformer has two secondary windings, which are connected as shown in Fig. 2. The secondary winding sides of the two high frequency transformers are connected in series to achieve dc link current balancing. Thus, rectified output voltage is the sum of the secondary voltages of high frequency transformers and each secondary voltage corresponds to its respective dc output voltage of each converter.

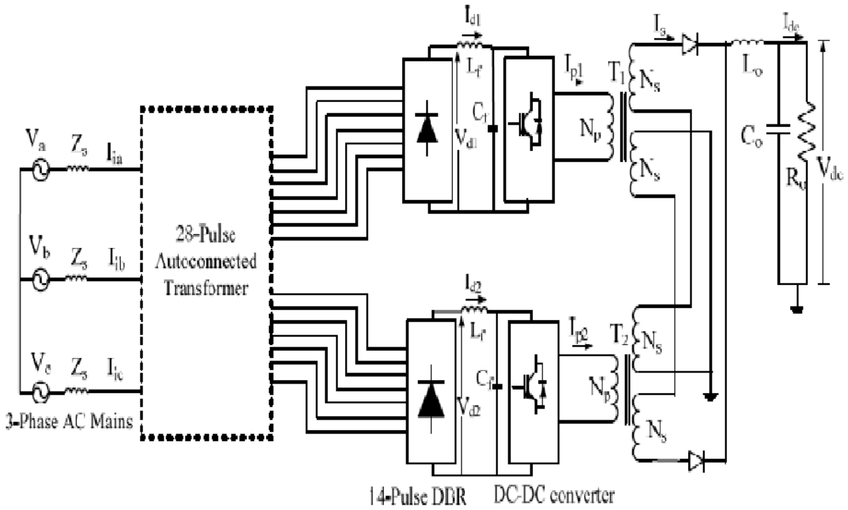


Figure 2: Structure of the overall SMPS system Configuration

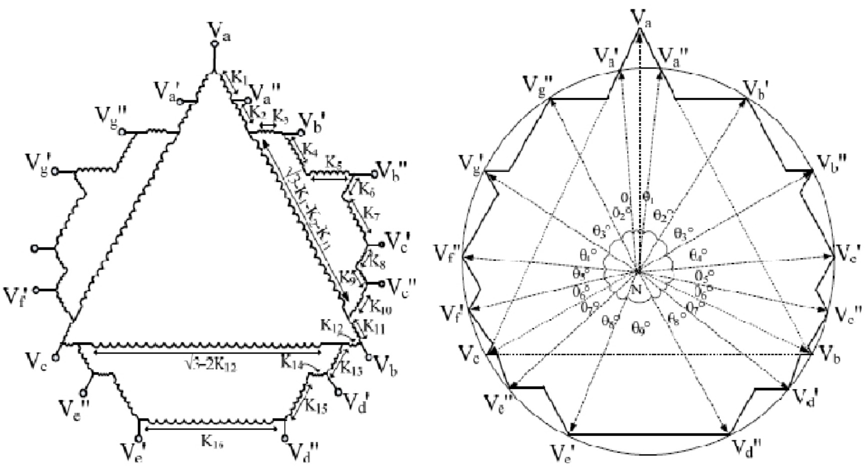
The overall output voltage characterize a two 14-pulse ac-dc converter output consisting of the sum of the two secondary winding voltages. Further, the stresses on the devices and the conduction losses in the diodes are reduced by choosing a centertapped connection for the high frequency transformer. A proportional-integral (PI) controller regulates the dc output voltage and also provides gating signal to the isolated full-bridge dc-dc converter.

Design of the Proposed 28-Pulse AC-DC Converter

The complete design of the proposed auto connected transformer based 28-pulse ac-dc converter is presented in this section. The ac-dc converter presented here is a combination of both multiphase and phase-staggering technique. In a multiphase system all the phases are distributed at same angle resulting in elimination of harmonics. In phase-staggering ac-dc converter technique, the phase angle displacement between ac supplies connected to bridges is given as, Phase angle displacement = 360°/ Number of pulses

Fig. 3a and 3b shows the winding diagram and phasor diagram of the proposed auto connected transformer. The phasor diagram depicts the angular position of various phasor. It means that for a 12-pulse ac-dc converter of 30° and for an 18-pulse ac-dc converter of 20º is the phase displacement between the rectifier bridges.

Similarly, if two seven-leg rectifier bridges are employed the phase staggering angle is considered as ((360°/14)/2) =12.86º. Therefore, two converters have a phase displacement of 12.86° between them. Thus, the phase angles of different phasor shown in Fig. 3b are given as θ1 = 6.43°; θ2 = θ4 = θ9 = 38.57°; θ3 = θ5 = θ8 = 12.86°; θ6= 10.71° and θ7 = 27.86° .The two seven-leg diode bridge converters 1 and 2 are connected to two sets of seven-phase secondary winding output terminals of the auto connected transformer. The converters 1 and 2 have each seven sets of voltage as a', b', c', d', e', f', g' and a'', b'', c'', d'', e'', f'', g'' respectively. These two sets of converters are displaced by 12.86° from each other at - 6.43º and +6.43° respectively from the input supply voltage of phase' a'.



(a) (b)

Figure 3: Winding and phasor diagram of proposed auto connected transformer based 28-pulse ac-dc converter.

The proposed auto connected transformer is designed by calculating the number of turns for each winding to produce a phase shift of ±6.43°. To calculate the number of the turns the following set of three-phase voltages and seven-phase voltages are considered.

$$Va=V\ 0^o,\ Vb=V\ -120^o,\ Vc=V\ +120^o \quad (1)$$

$$Va'=V\ +6.43^o,\ Vb'=V\ -45^o,\ Vc'=V\ -96.43^o,$$

$$Vd'=V\ -147.86^o,\ Ve'=V\ 199.28^o,$$

values of these constants determine the number of winding turns as a fraction of input ac mains voltage across the winding of the auto connected transformer. These values are used in simulation of auto connected transformer for a 28-pulse ac-dc converter.

$$Vf'=V\ -250.71^o,\ Vg'=V\ +302.14^o \quad (2)$$

$$Va''=V\ -6.43^o,\ Vb''=V\ -57.86^o,$$

$$Vc''=V\ -109.28^o,\ Vd''=V\ +160.71^o$$

$$Ve''=V\ +212.14^o,\ Vf''=V\ -263.57^o,$$

$$Vg''=V\ -315^o \quad (3)$$

$$Vab=\sqrt{3}Va\ 30^o,\ Vbc=\sqrt{3}Vb\ 30^o,$$

$$Vca=\sqrt{3}Vc\ 30^o \quad (4)$$

From the phasor diagram of auto connected transformer for 28-pulse ac-dc converter as shown in Fig. 3b the voltage equations for the converter 1 are as follows:

$$Va'=Va-K1Vca \quad (5)$$

$$Vb'=Va-(K1+K2)\ Vab+K3Vbc \quad (6)$$

$$Vc'=Vb'-K4Vab+K5Vbc+K6Vca-K7Vab \quad (7)$$

$$Vd'=Vb-K12Vbc+K13Vca \quad (8)$$

$$Ve'=Vc+(K12+K14)Vbc-(K13+K15)Vab \quad (9)$$

$$Vf'=Vc-K11Vca+K10Vab \quad (10)$$

$$Vg'=Va'+(K2+K4)Vca-(K3+K5)Vbc \quad (11)$$

In the same way, the voltage equations for converter 2 are

$$Va''=Va-K1Vab \quad (12)$$

$$Vb''=Va''-K4Vab+K5Vbc \quad (13)$$

$$Vc''=Vb+K11Vab-K10Vca \quad (14)$$

$$Vd''=Vd''-K14Vbc+K15Vca \quad (15)$$

$$Ve''=Vc+K12Vbc-K13Vab \quad (16)$$

$$Vf''=Vf''-K9Vca+K8Vab \quad (17)$$

$$Vg''=Va'+K2Vca-K3Vbc \quad (18)$$

Substituting equations (1)-(4) in equations (5)-(18).

The values of the constants K1 to K16 are found to be:

K1 = 0.2239, K2 = 0.3309, K3 = 0.4297, K4 =0.2022, K5 = 0.0.0386, K6 = 0.2248, K7 = 0.5188, K8 = 01759, K9 = 0.0762, K10 =0.0672, K11 = 0.2369, K12 = 0.3505, K13= 0.2921, K14 = 0.1458, K15 = 0.1122, K16= 0.6606.

The values of these constants determine the number of winding turns as a fraction of input ac mains voltage across the winding of the auto connected transformer. These values are used in simulation of auto connected transformer for a 28- pulse ac-dc converter.

Simulation Results of 6-Pulse and 28-Pulse AC-DC Converter Based SMPS.

Total harmonic distortion for 6-pulse ac-dc converter:

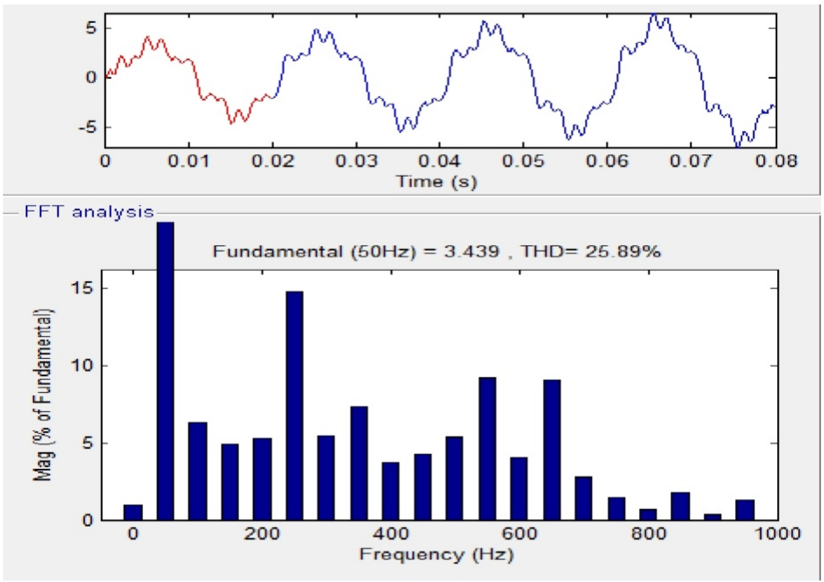


Figure 4.1: Input ac mains current (iia) along with its frequency spectrum for a 6-pulse ac-dc converter fed SMPS.

Total harmonic distortion for 28-pulse ac-dc converter at full load:

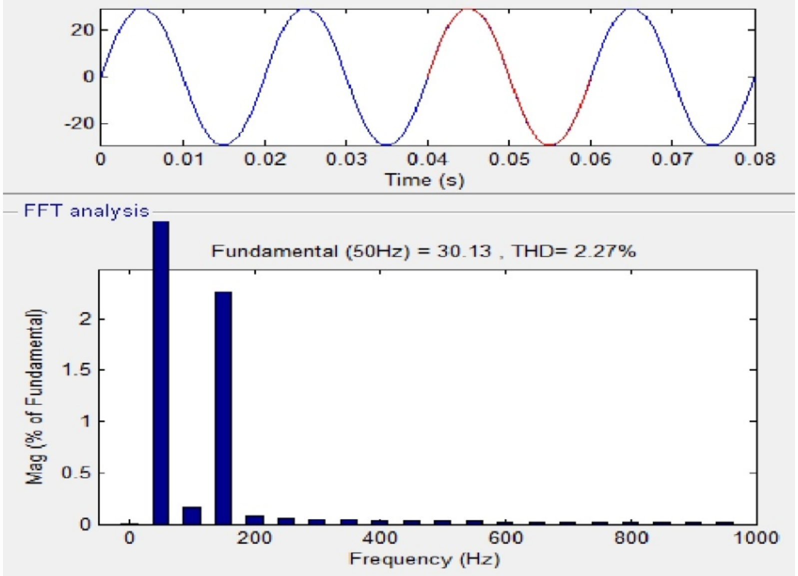


Figure 4.2: Input ac mains current (iia) along with its frequency spectrum for a 6-pulse ac-dc converter fed SMPS

Total harmonic distortion for 28-pulse ac-dc converter at full load:

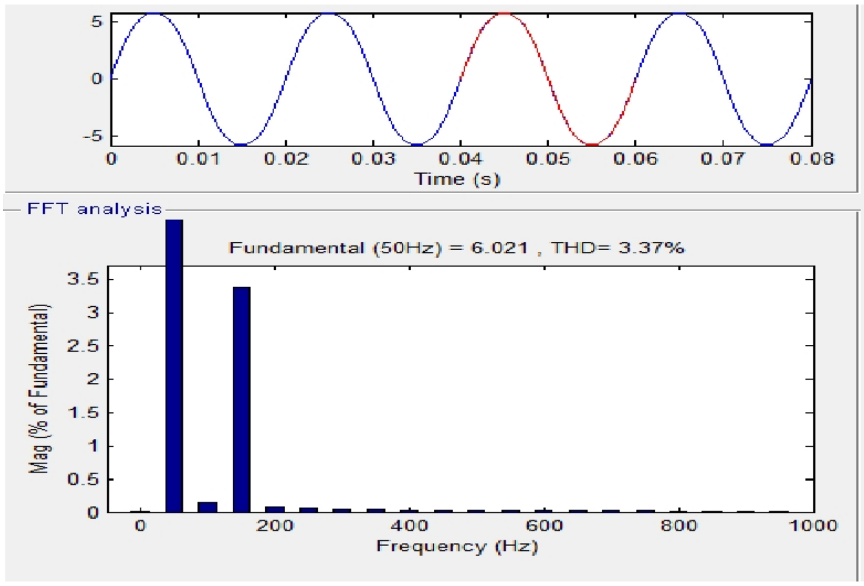


Figure 4.3: Input ac mains current (iia) along with its Frequency spectrum for 28-pulse ac-dc converter fed SMPS at light load.

Comparison between 6-Pulse and 28-Pulse AC-DC Converter based SMPS.

Table 1: comparison between 6-pulse and 28-pulse converter.

Pulse converters	%THD of Current	Input power factor
6-pulse	25.81	0.9521
28-pulse	2.27	0.9972

Table 2: Effect of load variation on power quality indices of the proposed 28-pulse AC-DC converter.

Load %	Iia (A)	ITHD (%)	Va(V)	VTHD (%)	Power Factor
20	6.021	3.37	220.5	1.06	0.9993
40	12.06	3.09	220.5	1.19	0.9989
60	18.1	2.83	220	1.65	0.9983
80	24.1	2.55	219.8	2.74	0.9977
100	30.13	2.27	218.8	3.15	0.9972

Appendix

Converter specifications;

Input supply voltage: 380V, 50Hz; DC output power: 12 kW (60V /200A) Switching frequency : 2 kHz

DC-link parameters: Lf = 4 mH, Cf = 1.4µF.

Output Inductor, Capacitor Lo =17µH, Co = 4000µF.

High Frequency Transformer specifications:

Primary turn, Np=17 Turns; Secondary Turn, Ns=1 Turn;

Controller Parameters: PI Controller Kp = 10; Ki = 0.15; Transformer rating: 1.64kVA, 380V/50Hz.

Conclusion

In this paper a 6-pulse ac-dc converter and 28-pulse ac-dc converter based SMPS are simulated and results are discussed above. This 28-pulse ac-dc converter gives less percentage THD and improved power factor compared to 6-pulse ac-dc converter. The 28-pulse ac-dc converter consist of bridge rectifier, auto connected transformer, inverter and pulse transformer. In this method the number of pulses obtained by using pulse transformer.

References

[1] D. A. Paice, "Power Electronic Converter Harmonic Multiples Methods for Clean Power," IEEE Press, New York, 1996.

[2] IEEE Recommended Practices and Requirements for Harmonics control in Electric Power Systems, IEEE Standard, 519, 1992.

[3] Bhim Singh, Sanjay Gairola, Brij N. Singh, Ambrish Chandra, Kamal Al-Haddad, "Multipulse AC-DC Converters for improving power quality: A Review," *IEEE Trans. on Power Electronics*, vol. 23, no.1, January 2008.

[4] Bhim Singh and S. Gairola , "A 40-Pulse AC-DC Converter Fed Vector-Controlled Induction Motor Drive,"*IEEE Trans.On Energy Conversion,* vol. 23, no.2, pp. 403- 411, June 2008.

[5] G. R. Kamath, D. Benson, and R. Wood, "A novel autotransformer based 18-pulse rectifier circuit,"in *Proc. 2001I EEE IECON*, *2001*, pp. 795–801

[6] J. H. Traver, C. H. Peng, M. A. Massoudi, and A. A. Dauhajre, "Multiphase low harmonic Distortion transformer, "U.S.Patent4- 779 181, Oct. 1988

[7] R. Hammond, L. Johnson, A. Shimp and D.Hurder,"A Magnetic Solutions to Line Current Harmonic Reduction, " in *Proc of IEEE Power Con., 1994*, pp. 354– 364.