American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-9, Issue-9, pp-15-24
www.ajer.org
Research Paper Open Access

Generation and suppression of Harmonics in ac system networks

[1]Onah A. J.and [2]EzemaE. E.
[1]Michael Okpara University of Agriculture, Umudike, Nigeria[2]Enugu State Polytechnic, Iwollo, Nigeria

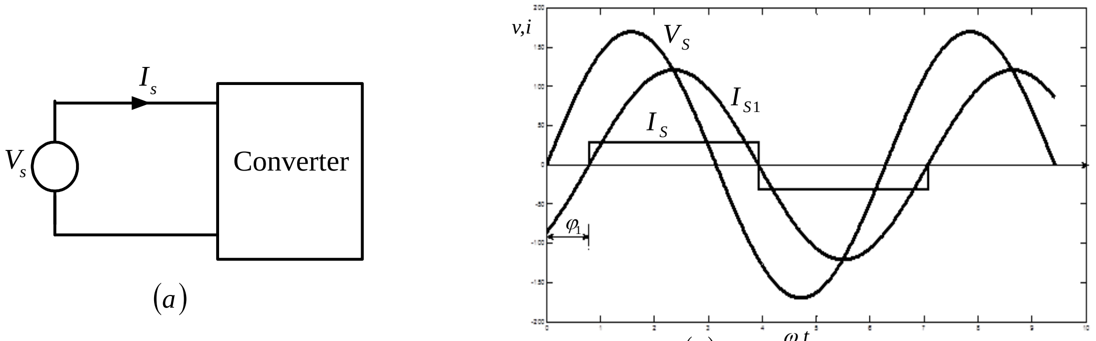
ABSTRACT
Majority of loads such as induction motors, battery chargers, static converters, light fittings, arc furnaces, transformers, cables, transmission lines and so on draw both sinusoidal currents and currents which are multiples of the supply frequency, commonly called harmonics. These harmonics are out of phase with the supply voltage. The sinusoidal currents generate active power (KW), which is transformed into mechanical power and heat. The harmonics, on the other hand, give rise to reactive power (KVar) which enables electrical machines like transformers and motors to operate by magnetizing their cores. However, reactive power flow in electrical networks has adverse effects depending on their magnitude and the nature of the supply network. How these harmonics are generated by nonlinear loads and how they can be kept low is the focus of this paper. Application of both passive and active filters to minimize these harmonics is presented in this paper. It is shown that the Application of these filters results in sinusoidal currents at nearly a unity power factor.

***KEY WORDS:* Non-linear loads, Harmonics, reactive power, power factor, filter.**

Date of Submission: 20-08-2020 Date of acceptance: 06-09-2020

I. INTRODUCTION

The total demand on the supply for a nonlinear load like induction motor is called apparent power; it is vector sum of both active and reactive components of power. The power factor is the ratio of active power to apparent power, and is given by $\cos\varphi$. φ is the angle between the fundamental components of voltage and current. When the current lags the voltage in phase rotation, the load is drawing reactive power from the source and power factor is said to be lagging. On the other hand when the current leads the voltage, the load is exporting reactive power to the source and the power factor is said to be leading. This power factor does not take into account the distortion caused by harmonics and so it is more accurately called displacement power factor (DPF). It is based on the fundamental quantities of voltage and current. 'True Power Factor', however, takes into consideration the effect that harmonic distortion may have on the voltage and current waveforms of a load (Bose, 2000). Fig. 1 shows a solid-state converter, as nonlinear load, drawing harmonic currents from ac mains.



(a) (b)

Fig. 1 Line voltage and current of a converter

(a) Circuit, (b) waveforms

V_s= fundamental rms voltage, I_s = supply rms current and I_{s1} = fundamental rms current. φ is the angle (displacement angle) between the fundamental components of the input current, I_{s1} and voltage, V_s

$$DPF = \frac{Active\ Power}{Fundamental\ rms\ voltage\ x\ Fundamental\ rms\ current} = \frac{P}{V_s\ I_{s1}} \quad (1)$$

$$= \frac{V_s\ I_{s1}\ \cos\varphi_1}{V_s\ I_{s1}} = \cos\varphi_1 \ (2)$$

$$Distortion\ \ factor,\ DF = \frac{rms\ \ value\ of\ \ fundamental\ current}{rms\ \ value\ of\ \ total\ current}$$

$$DF = \frac{I_{s1}}{\sqrt{I_{s1}{}^2 + \sum_{n=3,5,7,\cdots}^{\infty} I_{sn}{}^2}} \ (3)$$

'True Power Factor' is defined as:

$$PF = \frac{Active\ Power}{Supply\ rms\ \ voltage\ x\ Supply\ rms\ \ current}$$

$$= \frac{P}{V_s\sqrt{I_{s1}{}^2 + \sum_{n=3,5,7,\cdots}^{\infty} I_{sn}{}^2}} \ (4)$$

Combining equations (2), (3) and (4)

$$\frac{V_s I_{s1}\cos\varphi_1}{V_s\sqrt{I_{s1}{}^2 + \sum_{n=3,5,7,\cdots}^{\infty} I_{sn}{}^2}} = \frac{I_{s1}}{\sqrt{I_{s1}{}^2 + \sum_{n=3,5,7,\cdots}^{\infty} I_{sn}{}^2}}\cos\varphi_1$$

$$PF = \frac{rms\ \ value\ of\ \ fundamental\ current}{rms\ \ value\ of\ \ total\ current}\cos\varphi_1$$

$$PF = \frac{I_{s1}}{I_s}\cos\varphi_1 \ (5)$$

This power factor depends on the harmonics. Power factor can be high or low depending on the amount of harmonics injected into the system by nonlinear loads. Another important parameter used to measure the performance of a nonlinear load is the harmonic factor (HF) or total harmonic distortion (THD). It is a measure of the distortion of a waveform. It is given by the expression (Rashid, 1993).

$$THD = \sqrt{\frac{I_s^2 - I_{s1}^2}{I_{s1}^2}} \quad (6)$$

1.1. *Effects of Harmonics*

The transport of reactive power causes low power factor, voltage sag, network losses in the form of I^2R, resulting in the reduction of available network capacity. Hence the size of generation and transmission equipment is greatly increased. In three-phase networks these harmonics cause unbalance and excessive neutral currents. Harmonics give rise to interference in nearby communication networks and disturbance to other consumers. In electric motor drives, they cause torque pulsations and cogging (Dubey, 1989; Steeper, 1976).Filters prevent harmonic currents from entering the utility system, if harmonic-current-producing nonlinear loads are being supplied by the utility.This paper shows how these harmonics are produced, and how both passive and active filters are designed and appliedto minimize them in the utility.

II. METHODOLOGY

2.1 *Passive Filter*

Before the advent of modern power electronics, passive filters were extensively used to reduce the level of injected harmonics as shown in Fig.2

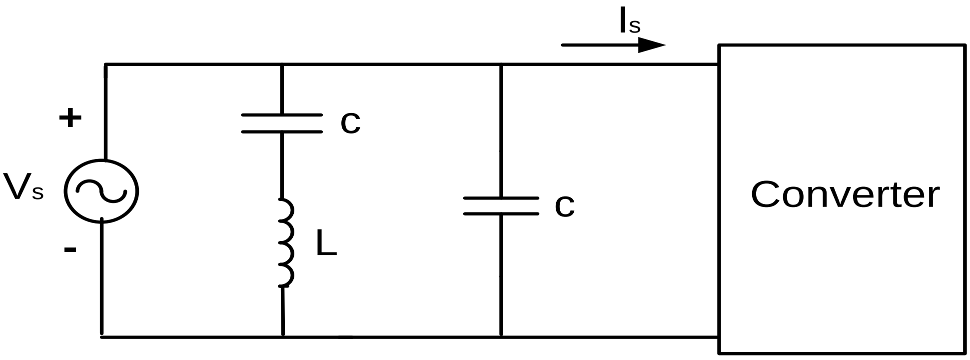


Fig.2 Passive filter

Conventionally, shunt passive L-C filters were used in static converters to reduce harmonics and improve power factor(Singh et al., 1999). The filters provide low harmonic impedance to ground. Moreover, they provide part of the reactive power consumed by the converter. Suppression of current harmonics results in the reduction of the rms supply current *I*s, and consequently power factor improvement. Fig. 3 is a single phase pulse-width modulation (PWM) voltage source inverter (VSI) (Agu, 2019; Hart, 1997). This is a nonlinear load. The output voltage waveform is shown in Fig. 4.

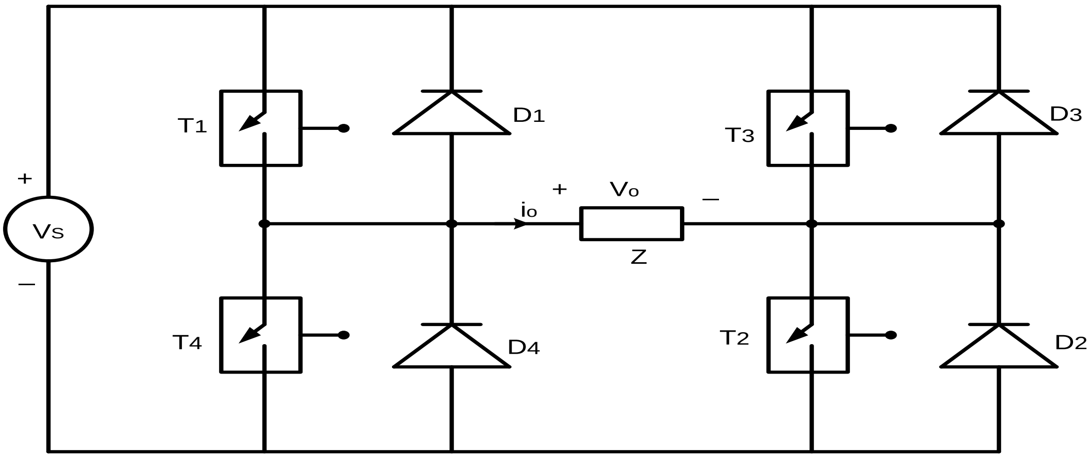


Fig. 3 single phase full bridge inverter configuration

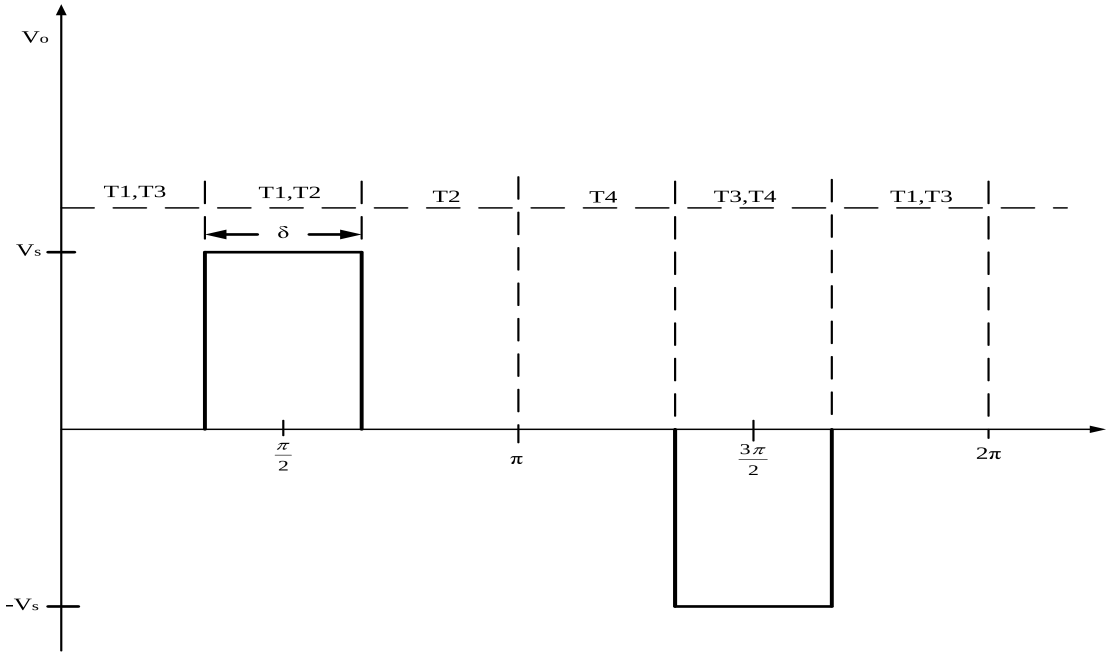


Fig.4 Output voltage waveform of the PWM voltage source inverter (VSI).

From Figure 4, the Fourier series of the output voltage, v_O is given as

$$v_o = \frac{V_s}{\pi}\left[\int_{\frac{\pi}{2}-\frac{\delta}{2}}^{\frac{\pi}{2}+\frac{\delta}{2}} \sin n\omega t\, d\omega t - \int_{\frac{3\pi}{2}-\frac{\delta}{2}}^{\frac{3\pi}{2}+\frac{\delta}{2}} \sin n\omega t\, d\omega t\right] \quad (7)$$

$$v_o = \sum_{n=1,3,5}^{\infty} \frac{4V_s}{n\pi} \sin\frac{n\delta}{2} \sin\frac{n\pi}{2} \sin n\omega t \quad (8)$$

$$i_o = \sum_{n=1,3,5}^{\infty} \frac{4V_s}{n\pi Z_n} \sin\frac{n\delta}{2} \sin\frac{n\pi}{2} \sin(n\omega t - \varphi_n) \quad (9)$$

Where

$$Z_n = \sqrt{R^2 + (nX)^2} \quad \varphi_n = \tan^{-1}\left(\frac{nX}{R}\right)$$

The output voltage, v_O and current, i_O are shown in Fig. 5, where V_S= 309V; $\delta = \frac{2\pi}{3}$

Load, Z = (1.5 + j3.14) Ω

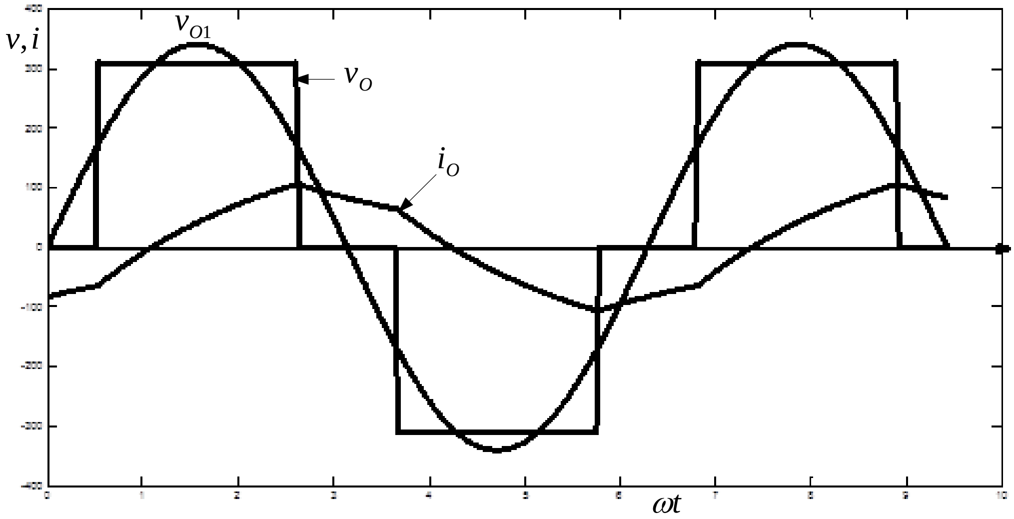


Fig. 5 Output voltage v_O and load current i_O

v_O and i_O have total harmonic distortion (THD) of 31% and 5.1 % respectively, Thus the output voltage of the inverter contains much harmonics. Filters can be used to smooth out the ac output voltage of the inverter. With filter inductance and capacitance added as shown in Fig.6, the load voltage, v_L and current, i_L assume the characteristics shown in Fig.7. The load voltage and current now have THD of 0.86% and 0.18% respectively, where, V_S = 259V, L = 10mH and C = 1000μF.

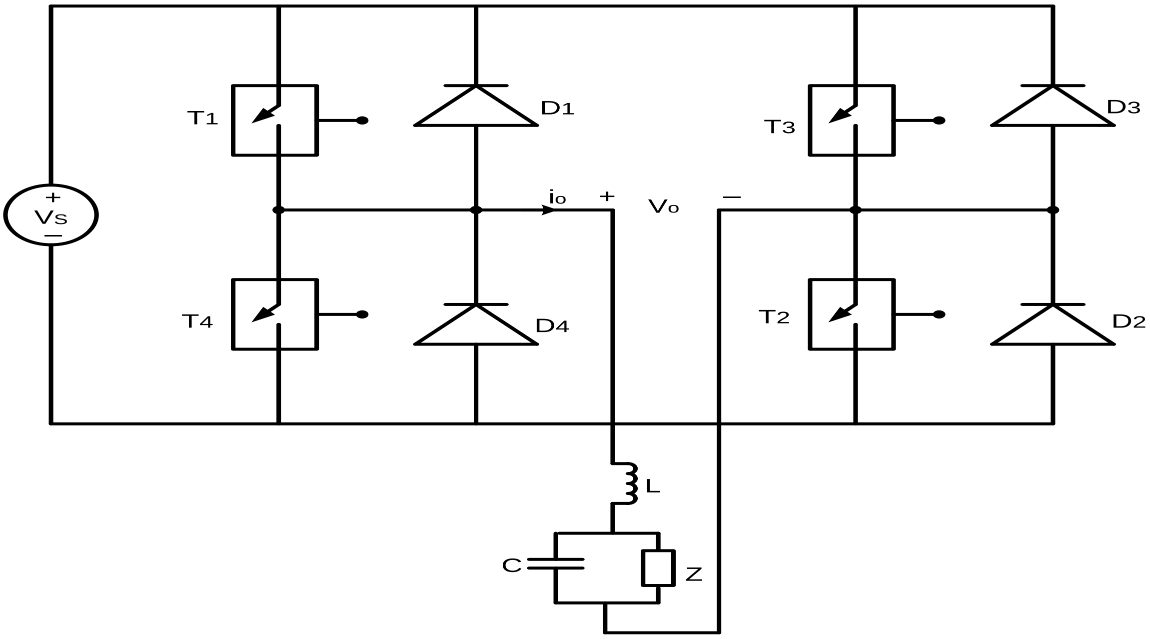


Fig. 6 Single phase full bridge inverter with passive filter

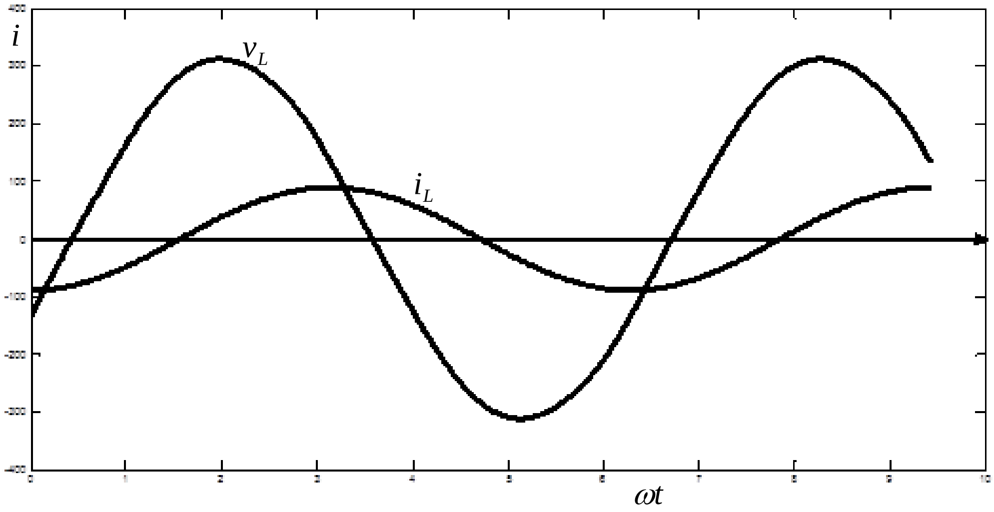


Figure 7 Load voltage and current

Fig. 8 shows the associated voltage and current waveforms of the system.

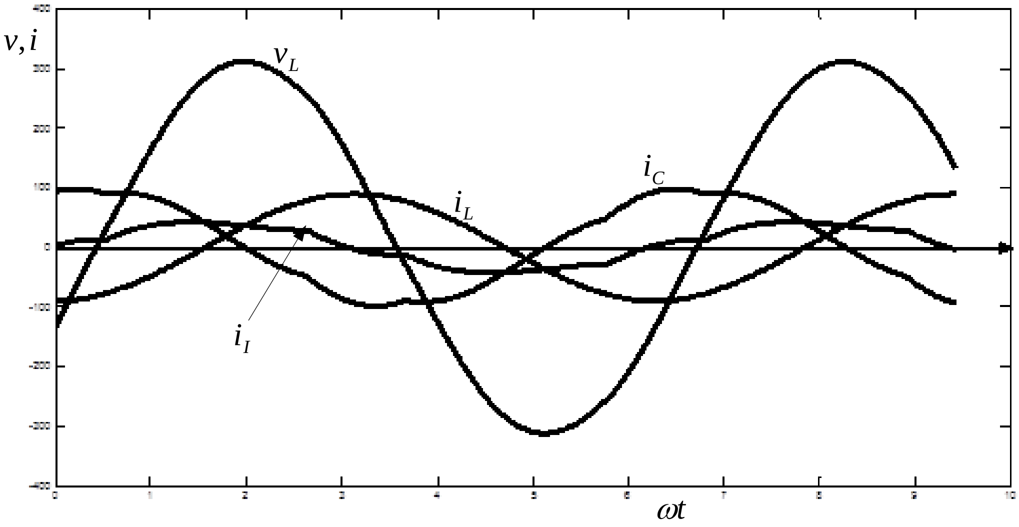


Fig. 8 Load voltage v_L, load current i_L, filter inductor current, i_I and filter capacitor current, i_C

2.2 Active Filter

However, in practical applications passive filters have some shortcomings. They are costly, bulky and often relatively inefficient. The increased severity of harmonic pollution in power networks has attracted the attention of power electronics and power system engineers to develop dynamic and adjustable solutions to the power quality problems. Such equipment, generally known as active filters (AFs) are also called active power line conditioners (APLCs), instantaneous reactive power compensators (IRPCs), active power filters (APCs), and active power quality conditioners (APQCs) (Miller, 1982; Paice, 1996).So, extensive research has developed active filters (AF) that are relatively lighter in weight, cheaper and more efficient (Nastran et al., 1994). Active filters prevent harmonic currents from entering the utility system, if harmonic-current-producing nonlinear loads are being supplied by the utility; thus producing sinusoidal currents at nearly a unity power factor. The first active filters put into use were line commutated thyristors converters in combination with some reactive components. But there was the problem of reliable controlled switching. Its effective use is only when it is force-commutated, under which condition it requires costly and complex external circuits that reduce circuit reliability. One of the major factors in the advancement of active filters technology is the advent of fast selfcommutating solid-state devices such as Gate-turn-off (GTO) thyristors, bipolar junction transistors (BJT), Power MOSFETs, and Insulated-gate bipolar transistors (IGBT). Active filters (AF) are inverter circuits, comprising of these active devices that can be controlled so as to act as harmonic current or voltage generators. Different topologies and control techniques have been developed. One of the commonest topology in use is the voltage-source inverter as shown in Figure 9. It is used at the load end to inject compensating current, opposite in phase to cancel harmonics or reactive components of the non-linear load current at the point of connection (Rim et al., 1995).

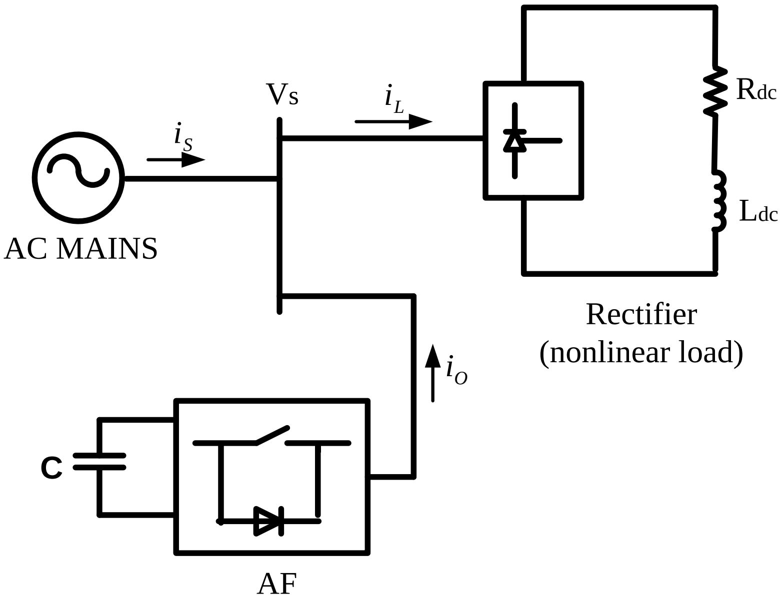


Figure 9 Voltage-fed-type AF

III. RESULTS AND DISCUSSION

3.1 *Nonlinear Load*

As nonlinear load, the most usual source of the supply harmonics and cause of poor power factor in ac mains is the phase-controlled rectifier, whether it is applied in the motor drive, battery charger, or in uninterruptible power supplies UPS (Katic and Graovac, 2002). Fig. 10 shows the circuit of a single-phase full rectifier.The rectifier draws pulsed, fluctuating current i_s from the utility grid. This non-sinusoidal currents cause significant harmonic pollution, and voltage drop across the finite internal grid impedance and the voltage waveform in the vicinity becomes distorted (Marafo et al., 2004; Allmeling, 2004). Harmonic current-free rectifiers capable of operating at unity power factor are required as utility interfaces for these inverter-based industrial loads (Srianthumrong, 2002).

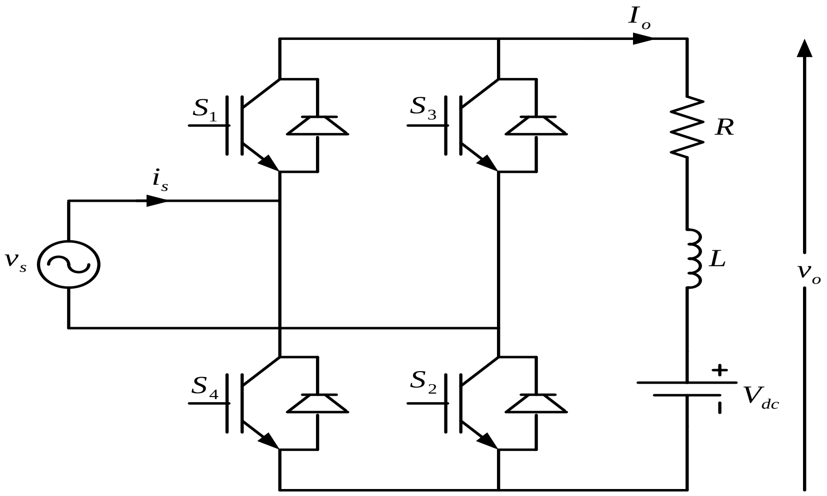


Fig. 10 Single-phase Full-Bridge Rectifier.

The Fourier series of the load current is:

$$i_s(t) = I_{dc} + \sum_{n=1}^{\infty} \left(a_n \cos n\omega t + b_n \sin n\omega t\right) \tag{10}$$

Equation (10) can be shown to be:

$$i_s(t) = \sum_{1,3,5}^{\infty} \frac{4I_o}{n\pi}\left[-\sin(n a)\cos(n\omega t) + \cos(n a)\sin(n\omega t)\right] \tag{11}$$

The source voltage v_S and current i_S are shown in Fig. 11, where α = 45°, R = 1.3Ω, L = 10mH, V_S = 220V, V_{dc} = 10V. The load current i_S has total harmonic distortion (THD) of 48.3%.The power factor is 0.64

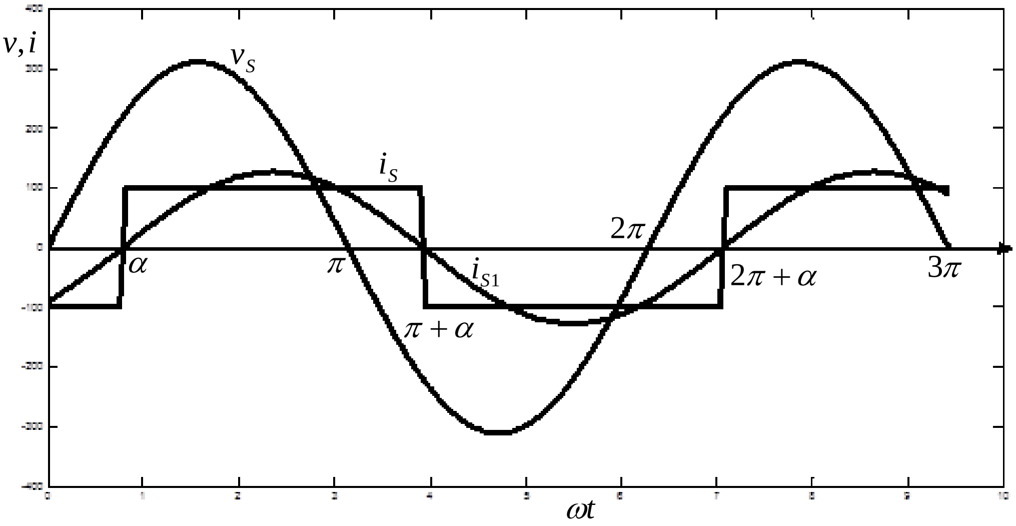


Fig. 11 Source voltage, v_S and load current, i_S waveforms

i_{S1} is the fundamental component of i_s.

The current drawn by the nonlinear load consists of a fundamental-frequency component i_{S1} and a distortion component i_S , known as harmonics. The load current is sensed and filtered to provide a signal proportional to the distortion component i_S .

3.2 *Active Filtering*

A switch-mode dc-to-ac converter, shown in Fig. 3, is operated to deliver the current i_S to the utility. Thus, in an ideal case, the harmonics in the utility current are eliminated.The circuit topology is as shown in Fig. 12.

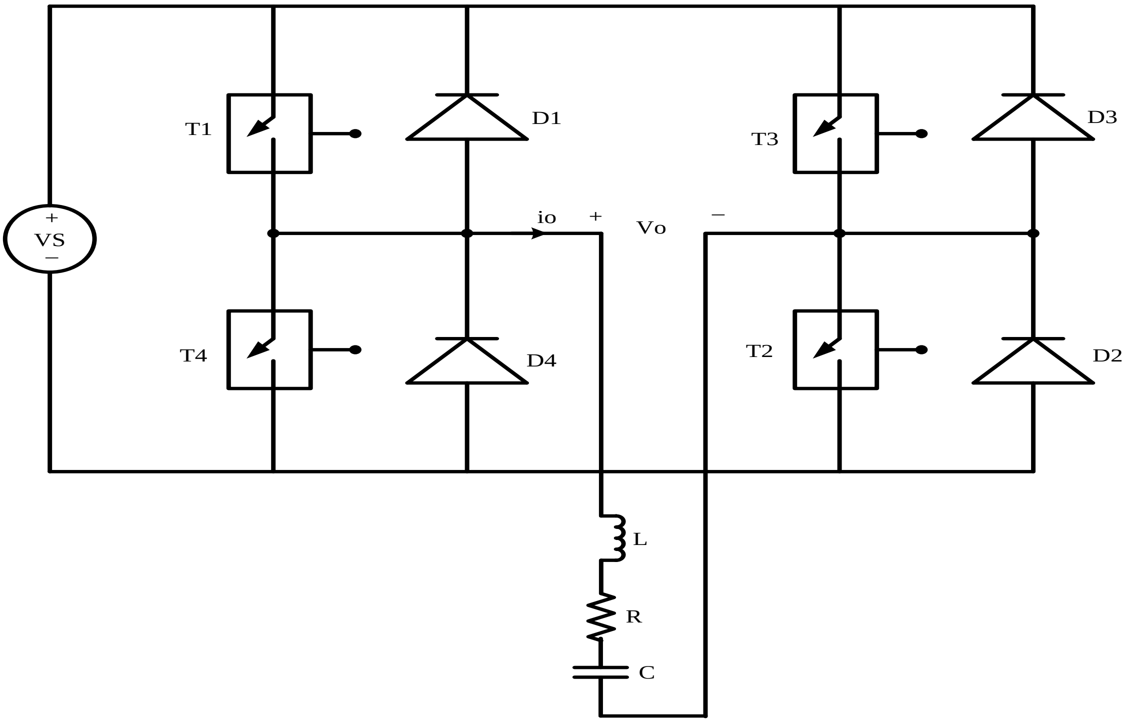


Fig. 12 single-pulse-width modulation full-bridge voltage source inverter

From equation (9), its output current is shown in Fig. 13, where V_S = 309V, $R = 1.5\Omega$, L = 25mH, C=370 µF, δ = 120°. The THD is 1.03 %. This current is the compensating current. It combines with the rectifier input current(i.e. $i_S + i_o$) in order to reduce the current harmonics present in the rectifier input current.

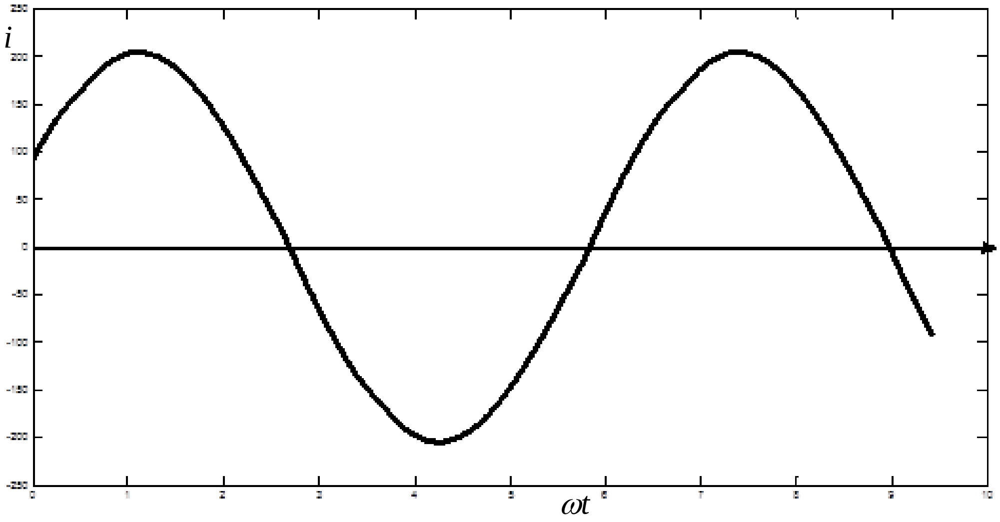


Fig.13 Output current (i_O) of the PWM VSI

After compensation, the rectifier input current becomes $i_L \left(i_L = i_S + i_O\right)$ appears as shown in Fig. 14. This is the compensated current with much less harmonics than the original rectifier input current. The THD is now 25.7%. So the THD of rectifier input current has dropped from 48.3 % to 25.7 %. The system power factor now hasrisen from 0.64 to 0.97

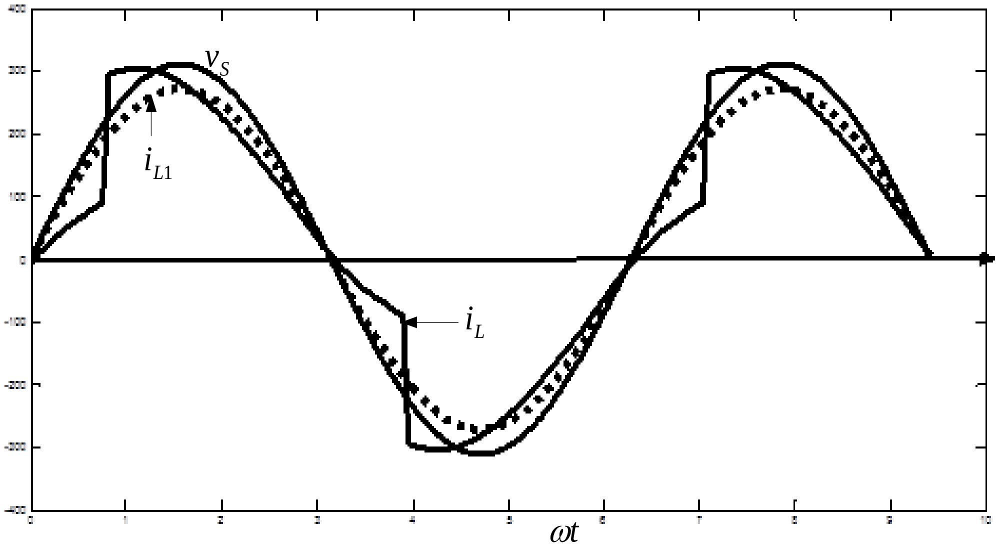


Fig. 14 Compensated Rectifier input current i_L and input voltage v_S

IV. CONCLUSION

Nonlinear loads draw harmonic and reactive power components of current from ac mains. The effects of harmonics and reactive power flow in ac systems are quite undesirable.Hence passive L-C filters were employed to reduce harmonics and capacitors were applied to improve the power factor of the ac loads. Passive filters have the disadvantages of bulkiness, resonance and fixed compensation. Therefore, the increased severity of harmonic pollution in power networks has led to the development of the equipment known as active filters, as dynamic and adjustable solutions to the power quality problems. It has been shown in this paper that PWM voltage-source inverter, as an active filter, can significantly minimize harmonic pollution in ac system network. The AF reduced the THD of supply current from 48.3 % to 25.7 %, and raised the system power factor from 0.64 to 0.97.

REFERENCES

[1]. Bose, B. K. (2000). Modern Power Electronics and AC Drives. Prentice Hall,
[2]. Rashid, M. H. (1993). Power Electronics: Circuits, Devices, and Applications. 2nded. New Jersey:
[3]. Prentice Hall Inc., pp. 54.
[4]. DubeyG.K. (1989).Power Semiconductor Controlled Drives. New Jersey: Prentice Hall Inc., pp. 285-290.
[5]. Steeper, D. E. and Stratford, R.P., (1976).Reactive Compensation and Harmonic Suppression for Industrial Power Systems Using Thyristor Converters. IEEE Transactions on Industry Applications, 12, pp. 232-254.
[6]. Singh, B., Al-Haddad, K., and Chandra, A.(1999).A Review of Active Filters for Power Quality Improvement. IEEE Transactions on Industrial Electronics, 46, pp. 960-971.
[7]. Agu, M.U. (2019). Principles of Power Electronics.Nsukka: University of Nigeria Press., pp. 460-475.
[8]. Hart, D.W. (1997). Introduction to Power Electronics. New Jersey: Prentice-Hall, Inc., pp. 308-328.
[9]. Nastran, J., R. Cajhen, R., Seliger, M., and Jereb, A. (1994).Active Power Filters for Nonlinear AC loads. IEEE Trans. Power Electronics, 9, pp. 92-96.
[10]. Miller, T.J.E. (1982). Reactive Power Control in Electric Systems. Toronto: Wiley, pp. 32-48.
[11]. Paice, D.A. (1996). Power Electronic Converter Harmonics-Multipulse Methods for Clean Power. New York: IEEE Press.
[12]. Rim, G.H., Kang, Y., Kim, W. H., and Kim, J. S. (1995).Performance improvement of a voltage source active filter.In: Proceedings IEEE APEC, pp. 613-619.
[13]. Katic.,V. A., andGraovac, D. (2002).A Method for PWM Rectifier Line Side Filter Optimization in Transient and Steady State. IEEE Transaction on Power Electronics, 17, pp. 342-352.
[14]. Marafo, J. A. G., Pomilio, J.A., and Spiazzi, G. (2004). Improved Three-Phase High-Quality Rectifier with Line-Commutated Switches. IEEE Transaction on Power Electronics, 19, pp. 640-648.
[15]. Allmeling, J. (2004). A control Structure for Fast Harmonics Compensation in Active Filters. IEEE Transaction on Power Electronics, 19, pp. 508-514.
[16]. Srianthumrong, S., Fujita, H. and Akagi, H. (2002).Stability Analysis of a Series Active Filter Integrated with Double-Series Diode Rectifier. IEEE Transaction on Power Electronics, 17, pp. 117-124.

Onah A. J. "Generation and suppression of Harmonics in ac system networks." *American Journal of Engineering Research (AJER)*, vol. 9(9), 2020, pp. 15-24.