A Comparative Analysis of Supply Side Power Factor in Phase Angle Controlled AC to AC Voltage Converters

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Abstract

This paper presents the analysis of supply side power factor in a non-sinusoidal environment. For this purpose, single phase bidirectional and unidirectional AC voltage regulators are considered and operate with resistive loads. The phase angle control technique is used to switch on and off the thyristors connected in these converters. The experimental setup was made to measure the supply side power factor and the total harmonic distortion by using power quality analyzer. Finally, a comparison of the power factor on source side and the harmonics in both AC voltage regulators is made. It is concluded from the results that input side power factor of these converters is less than unity even at resistive loads due to generation of harmonics.

Keywords
AC voltage converters, phase-angle control, Supply side Power Factor, Harmonics

1. Introduction

Power electronics is an emerging technology that found various applications due to the improvement in the number of converters. This improvement due to rapid invention in power semiconductor devices. These converters found applications in wind farms, solar systems, fuel cells, vehicles, switch mode power supplies, mobile chargers, dc drives systems, wireless power transfer, computer systems, and telecommunication equipment, etc. (Acharya et al., 2016; Bimal, 2014; Buzdugan and Balan, 2017; Blaabjerg et al., 2005; Chang et al., 2013; Van Wyk, 2000; Haiping et al., 2004).
The power electronic converters are basically variable structure systems that contain nonlinearities because of switching operation. The harmonics are generated in these converters due to the switching action that badly affect their performance. The generated harmonics leads the problems in system networks, such as distortion in the line voltages, overloading of the power system equipment, errors in the metering and protecting equipment and badly affect the power factor (PF) of supply side (Li and Mi, 2015; Lu et al., 2008; Larik et al., 2011; Mahar et al., 2011; Moreira et al., 2015; Nabil et al., 2004).
In this paper, the PF of unidirectional and bidirectional converters is compared. The power factor of both converters was measured using the 43B fluke power quality analyzer (PQA). In addition, the measured results were analyzed with the help of fluke view software.

2. Experimental arrangement

Figure 1 illustrates the block diagram of an experimental setup that consists of SACED TECHNEL unit, PQ analyzer and the workstation with fluke view software. The SACED-TECNEL unit was used to test the phase angle controlled AC voltage converters. This unit also has the ability to activate the solid state switches of electronic power converters through its labview-based program. The testing of unidirectional converter is not available in the programming of SACED-TECNEL unit. Therefore, this additional converter was successfully tested with simple modification in this unit. These AC voltage converters were tested with 220V AC source voltage. The complete view of the experimental configuration is shown in Figure 2.

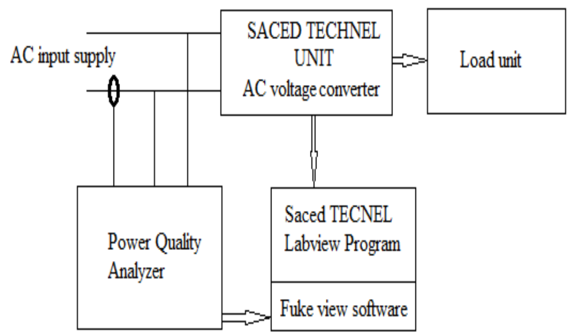

Figure 1. Block diagram of an experimental setup

Figure 2. Experimental setup

3. Power Factor

Power Factor (P.F) under sinusoidal conditions is given by Eq. (1) (Li and Mi, 2015; Rashid, 2004; Subjak and Mcquilkin, 1990; Sarlioglu et al., 2017; Willems, 2004).

$$P.F = \frac{Vs * Is * Cos\Phi}{Vs * Is} \dots\dots (1)$$

Where, Vs and Is are rms input voltage and current respectively.
Power Factor under Non-sinusoidal condition is given by Eq. (2)

$$P.F = \cos\emptyset_1 \times \frac{I_F}{I_L} \dots \dots\dots\dots\dots\dots (2)$$

Where,
I_F and I_L are the rms fundamental component current and rms load current respectively.
$\emptyset_1$ is angle between supply voltage and current of fundamental component.

4. AC Voltage Converters

These converters obtain variable output voltage from fixed AC input voltage. They are classified as unidirectional and bidirectional converters (Moreira et al., 2015; Zare, 2014). The unidirectional converter is also called a half-wave AC voltage controller. The circuit diagram of unidirectional regulator is given in Figure 3. The bidirectional or fullwave AC voltage converter is combination of two anti parallel thyristors. The circuit arrangement of bidirectional converter is illustrated in Fig. 4.

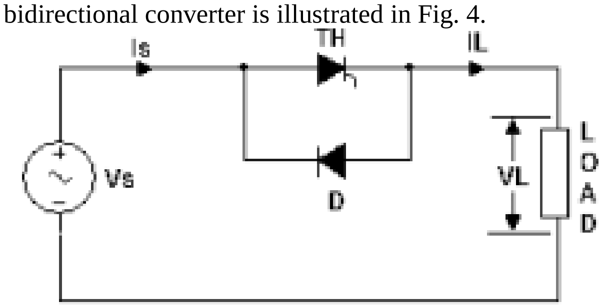

Figure 3. Single phase unidirectional AC voltage converter

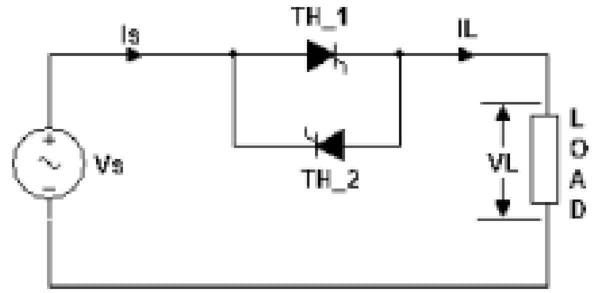

Figure 4. Single phase bidirectional AC voltage converter

5. Results and Discussion

The power factor of source side and the total harmonic distortion in line current of unidirectional as well bidirectional ac voltage converters at various firing angles were measured by using power quality analyzer. Both converters tested at resistive loads and the results are measured and tabulated in Table 1.

Table 1. Results of AC voltage converters

SR.#	Firing Angle	Unidirectional ac voltage converter		Bidirectional antiparallel ac voltage converter	
		P.F	THDi %	P.F	THDi %
1	30º	0.99	7.8	0.99	11.3
2	60º	0.97	24.1	0.92	33.6
3	90º	0.91	41.5	0.74	61.5
4	120º	0.86	54.3	0.47	100.3
5	150º	0.89	51.5	0.18	170.3

The SCRs of both converters are triggered by the labview based program of SACED TECHNEL system. The Figure 5 and Figure 6 show the labview based waveforms of unidirectional and bidirectional converters respectively.

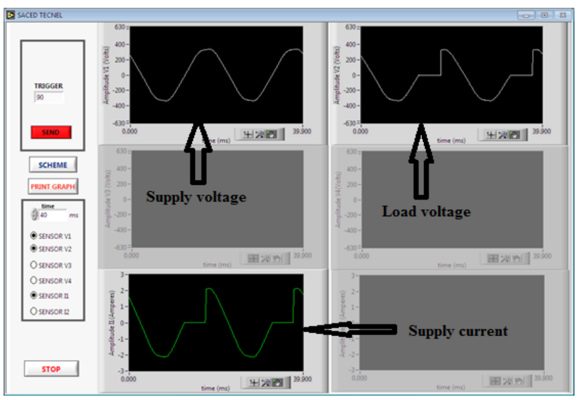

Figure 5. Virtual waveform of unidirectional converter

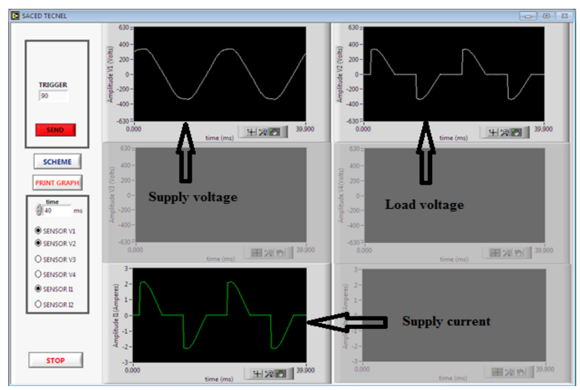

Figure 6. Virtual waveform of bidirectional converter

The waveforms and the harmonic of both converters were also captured and then analyzed in fluke view software. The supply voltage and the current waveforms at the 90° firing angle of the unidirectional converter are shown in Figure 7. Moreover, it also indicates various parameters, including PF and displacement power factor DPF. It can be seen from the waveform that there is no any distortion in the supply voltage, but the current waveform is distorted. The harmonic spectrum of the distorted waveform is shown in Figure 8 which indicates the percentage of total harmonic distortion.

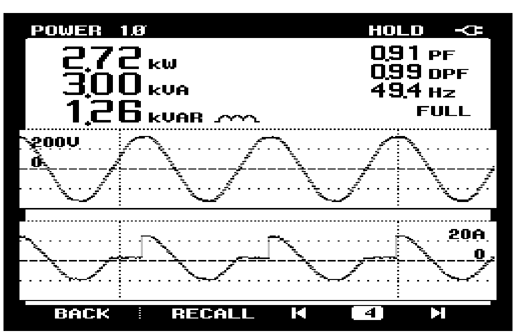

Figure 7. Supply voltage & current waveform of unidirectional converter

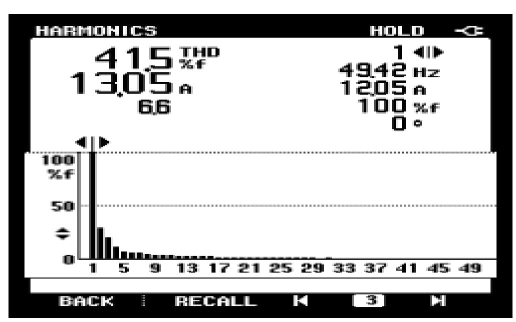

Figure 8. Supply current harmonic spectrum of unidirectional converter

Similarly, the waveforms and the supply current harmonic spectrum of the bidirectional converter at the firing angle of 90° are illustrated in Figure 9 and Figure 10 respectively. The distortion is also present in the supply current. The supply side PF is 0.74 as shown in Figure 9 that is 0.17 less than the unidirectional converter at same 90° firing angle. Moreover, the DPF of bidirectional controller is also less than the unidirectional converter.

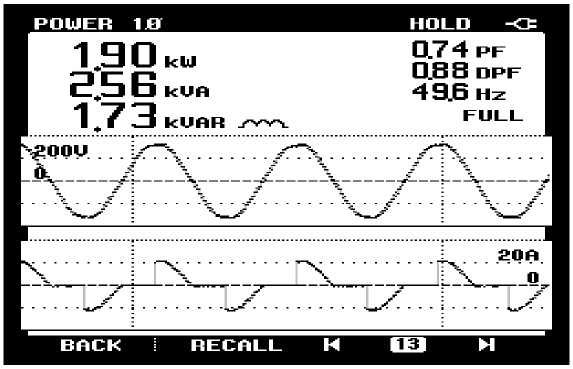

Figure 9. Supply voltage & current waveform of bidirectional converter

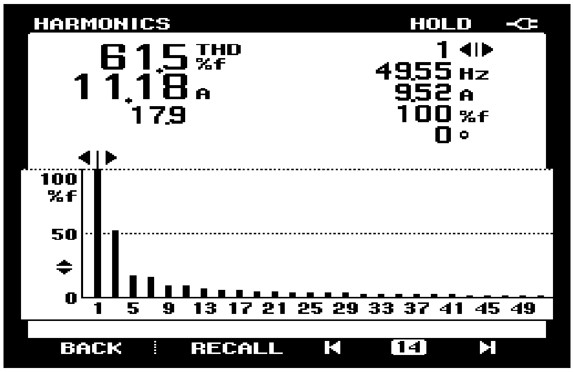

Figure 10. Supply current harmonic spectrum of bidirectional converter

The comparision of PF at different firing angles of both converters is ploted in Figure 11. It is clear from the ploted as well as recorded results of Table 1, that the supply power factor of these converters are affected even with resistive loads. The power factor of these converters decreses as the distotion in the spply current is increses. The total harmonic distortion results of these converters are plotted in Figure 12. During the test, it was also observed that the supply side DPF of single phase unidirectional ac voltage converter is not affected.

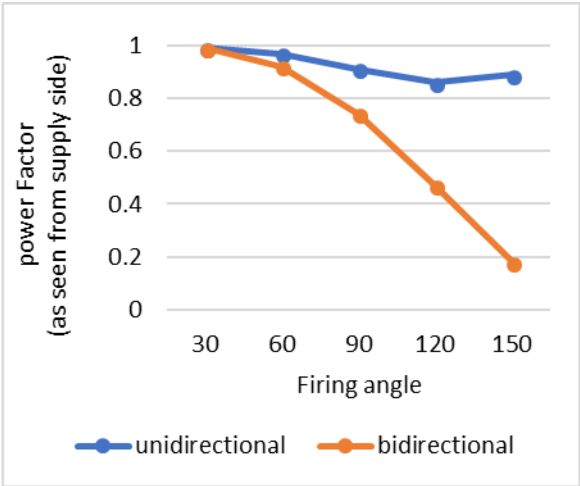

Figure 11. Results of supply side power factor against firing angle

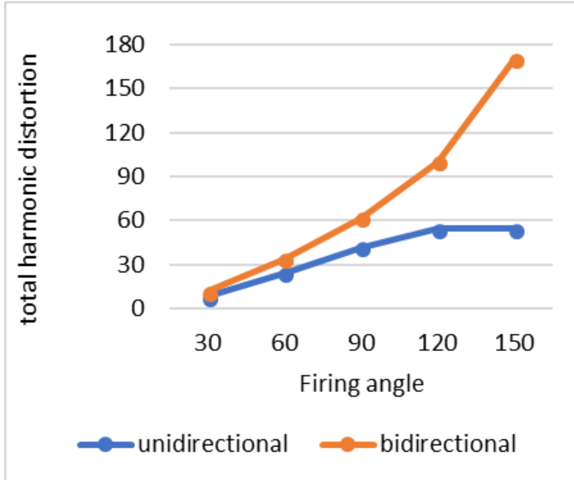

Figure 12. Results of THD in supply current against firing angle

6. Conclusion

In this work, a comparison of the supply side of unidirectional and bidirectional single phase AC voltage converters has been investigated. It is concluded from the measured results that the power factor of the source remain unity due to harmonics even at resistive loads. The power factor of unidirectional converter is less affected compared to bidirectional converter. It is also concluded that the DPF of unidirectional converter is not affected even if the distortion is increased.

References

Acharya, S., Ghosh, R., and Halder, T., An adverse effect of the harmonics for the power quality issues, 2016 International Conference on Computational Techniques in Information and Communication Technologies (ICCTICT), pp. 569-574, New Delhi, India, 11-13 March, 2016.

Ahmed, N.A., and El-Zohri, E,H., Power Factor Improvement Of Single Phase AC Voltage Controller Employing Extinction Angle Control Technique, In Circuits and Systems, IEEE 46th Midwest Symposium on vol 3, pp.1075-1080, 2004.

Bimal, K., Energy, Global Warming and Impact of Power Electronics in the Present Century, Power Electronics for Renewable Energy Systems, Transportation and Industrial Applications, pp. 1-26, 2016.

Buzdugan, M.I. and Balan, H., Power system harmonics issues in some end user facilities, 52nd International Universities Power Engineering Conference (UPEC), pp. 1-6, Heraklion, Greece, 28-31 August, 2017.

Blaabjerg, F., Consoli, A., Ferreira, J.A., and Van Wyk, J.D., The future of electronic power processing and conversion, IEEE Transaction on Industry Applications, 2005, vol. 20, no.3, pp. 715-720, 2005.

Chang, C.H., Chang, E.C., and Cheng, H. L., A high-efficiency solar array simulator implemented by an LLC resonant DC–DC converter, IEEE Transactions on Power Electronics, 2013. vol. 28, no.6, pp. 3039-3046, 2013.

Van Wyk,J.D., Power electronics technology at the dawn of a new century-past achievements and future expectations, 3rd international Power Electronics and Motion Control Conference, vol.1, pp. 9-20, , Beijing, China, 15-18 August, 2000.

Haiping, Xu, Kong, Li, and Xuhui W., Fuel cell power system and high power DC-DC converter, IEEE Transactions on Power Electronics, vol.19, no. 5, pp. 1250-1255, 2004

Li, S. and Mi, C.C., Wireless power transfer for electric vehicle applications. IEEE journal of emerging and selected topics in power electronics, vol.3, no.1, pp.4-17, 2015.

Lu, D|.D.C., Iu, H.H.C, and Pjevalica, V., A Single-Stage AC/DC Converter With High Power Factor, Regulated Bus Voltage and Output Voltage, IEEE Transactions on Power Electronics, vol.23, no.1, pp. 218-228, 2008.

Larik S.A., Mahar M.A. and Shaikh A.R., Performance Analysis of Phase Controlled Unidirectional and Bidirectional AC Voltage Controllers, Mehran University Research Journal of Engineering and Technology, Jamshoro, Pakistan, vol. 30, no.1, pp. 151 – 158, 2011.

Mahar M.A., Uqaili, M. A., and Larik S.A., Harmonic Analysis of AC-DC Topologies and their Impacts on Power Systems". Mehran University Research Journal of Engineering and Technology, Jamshoro, Pakistan, vol. 30, pp. 173 – 178, 2011.

Mahar M.A, Larik A.S., and Shah S.A.A, impacts on Power Factor of AC Voltage Controllers under Non-Sinusoidal Conditions, Mehran Research General of Engineering & Technology, vol.31, no.2. 2011.

Moreira, A.C., Deckmann, S.M., Marafão, F.P., da Silva, L.C.P. and Paredes, H.K.M., Methodology for defining effective power factor compensation in three-phase systems. In Nonsinusoidal Currents and Compensation (ISNCC), 2015 International School on IEEE. pp. 1-6, 2015

Rashid, M., Power Electronics: Circuits, Devices, and Applications, 3rd Edition, Prentice Hall New Jersey, USA, 2004.

Subjak, J.S., and Mcquilkin, J.S., "Harmonics-Causes, Effects, Measurements, and Analysis: An Update", IEEE Transactions on Industry Applications, Volume 26. No. 6, pp. 1034-1042, USA, 1990.

Sarlioglu, B., Morris, C.T., Han, D. and Li, S, Driving toward accessibility: a review of technological improvements for electric machines, power electronics, and batteries for electric and hybrid vehicles. IEEE Industry Applications Magazine, vol.23, no.1, pp.14-25. 2017.

Willems, J.L., Reflections on Apparent Power and Power Factor in Nonsinusoidal and Polyphase Situations, IEEE Transactions on Power Delivery, vol.19, no. 2, pp. 835-840, 2004.

Zare, F., Harmonics issues of three-phase diode rectifiers with a small DC link capacitor, 16th International Power Electronics and Motion Control Conference and Exposition (PEMC), pp. 912-917, Antalya, Turkey, 21-24 September, 2014.

Biographies

Abdul Sattar Larik was born in Larkana, Sindh, Pakistan, in 1973. He received the B.E. degree in Electrical Engineering in 1999, M.E. in Electrical Power Engineering in 2005 and PhD Power Electronics and Control Engineering under the Indigenous Ph.D. Program in 2009 from Mehran University of Engineering &. Technology Jamshoro. He has been working there as a Professor since 2012. Currently his research interest includes the area of Power Electronics Converters, Sliding Mode Controller, and Power Quality.

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