Harmonics Analysis of Single-Phase Shunt Active Power Filter Using Parabolic PWM for Current Control

Bharat Hari Shivhare[1], Dr. Manju Gupta[2], Prof. Neeti Dugaya[3], Prof. Mamta Sood[4]
[1]M. Tech Scholar, Department of Electrical & Electronics Engg. OIST Bhopal (India)
[2 3 4]Assistant Professor, Department of Electrical & Electronics Engg. OIST Bhopal (India)

Abstract: *In this paper a single phase active power filter is connected to a single phase grid with non-linear load. The single phase active power filter mitigates the harmonics generated by the non-linear load connected at PCC. The harmonics generated by the non-linear load are redirected to active power filter direction so as to avoid injection into the source damaging it. The novel single phase active power filter has half bridge connected to share capacitors. The two power electronic devices of the active power filter are controlled by parabolic PWM with feedback from the source voltage and load current for compensation of harmonics in source current. The conventional PI controller is updated with fuzzy logic controller for further reduction of harmonics. The circuit of both the controllers with active power filter connected to single phase grid is modelled in MATLAB Simulink environment with graphs generated with respect to time.*

Keywords: Fuzzy logic controller, PWM, Active Power Filter.

Introduction

Filters are the networks that possess the property of differentiating between the signals of various frequencies and passing the signals of specific frequency only while the signals of the other frequencies not belonging to this range are suppressed or attenuated. The frequencies that are allowed to pass through the filters are termed as pass band and the frequencies that are totally suppressed or attenuated are termed as stop band or attenuation band. The frequency that separates the stop band and pass band is termed as cut-off frequency. Filters are classified on the basis of working characteristics, application field, relation between arm impedances, frequency characteristics etc. On the basis of its application field the filters are classified as follows:
Passive filters Active filters Hybrid filters

1.2 Introduction to Electrical Power Quality

Electric power quality can be described as the degree to which the voltage, frequency and waveform of a power supply system match to established specifications. A good power quality can be stated as a steady supply voltage that remains within the prescribed range, a steady ac frequency that is close to the rated value and smooth voltage curve waveform preferably a sinusoidal wave. In other words it can also be stated as the compatibility between output of an electric outlet and the plugged in load. In absence of proper power, an electrical device tends to malfunction, prematurely fail or not at all operate. While "power quality" is a suitable term but actually it is the quality of the voltage rather than power or electric current that is actually described by it.
The power quality may be expressed as a set of values of parameters, such as:

- Continuity of service irrespective of voltage sag/swell

- Voltage magnitude variations
- Transient currents and voltages
- Harmonics in the waveforms

Compatibility is the major term associated with power quality and the problems associated with it usually have two solutions: i.e. either to clean up the power or to make the equipment stronger.

The CBEMA curve, gives the characteristics of tolerance of data-processing equipment to voltage variations, and also gives the duration and magnitude of voltage variations that can be tolerated. (CBEMA Curve: Ideally, an AC voltage is supplied in form of a sinusoidal waveform having an amplitude and frequency given by national standards or system specifications with an impedance of zero ohms at all frequencies.)

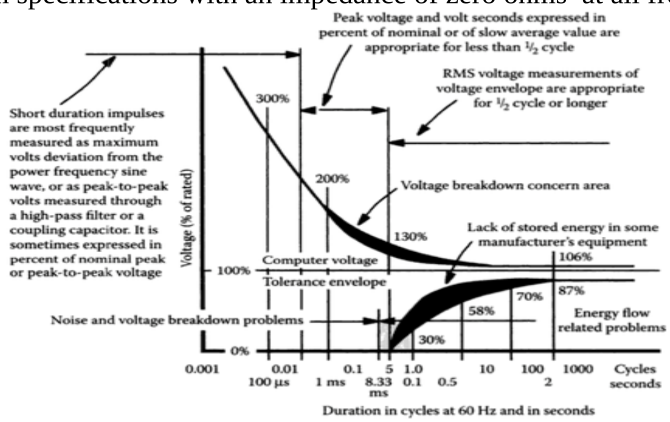


Fig. 1: CBEMA Curve.

1.3Power Quality Deviations

It is impossible to find an ideal power source in real life and generally power quality can deviate in the below mentioned ways:

a) Voltage

- Variations in the values of peak or RMS voltage (voltage sag/swell)
- Flickering: rapid visible changes of light level that leads to random or repetitive voltage variations.
- Spikes, impulse or surges: brief and abrupt increases in voltage
- Under voltage: when the nominal voltage drops below 90% for more than 1 minute.
- Overvoltage: occurs when the nominal voltage rises above 110% for more than 1 minute.

b) Frequency

- frequency variations
- Non zero low-frequency impedance
- Nonzero high-frequency impedance
- Harmonics at lower frequencies
- Inter harmonics at higher frequencies

c) Waveform

- Usually oscillations of voltage and current follow a sine or cosine function form, however due to imperfections in the generators or loads there occurs variations.
- In general, generators causes voltage distortions and loads causes current distortions, that are more rapid than the nominal frequency, and are termed as harmonics.
- The distortion of the ideal waveform due to harmonics is termed as total harmonic distortion (THD).
- These waveform distortions can cause vibrations, buzzing, losses and overheating.

II. Parabolic PWM For Current Control

Current control of a PWM converter is one of the majortopics of modern power electronics. In most power converter applications, like ac power supplies, active power filters (APFs) and PFC converters there is a requirement of accurate current control with high dynamic performance. Fundamentally, the current control schemes can be classified into two groups: 1) direct tracking error control through PWM and 2) indirect current control where the current error is fed to a controller to generate the converter voltage command. Generally, the stability and dynamic performance of the second method are inferior to those of direct current PWM due to the limited bandwidth of the current control loop. There are various direct current control PWM methods in the literature. The primary group of methods is based on direct current error control that includes hysteresis control, synchronized on–off control and ramp comparison. These method features simple implementation and good current regulation dynamics. The switching frequency variation is a major drawback of this method. Even though to maintain a fixed switching frequency, various approaches have been proposed like using a phase-locked loop, feeding back the peak current error, detecting zero crossing of current or current error, feeding forward the current error slope or through fully digital implementation with adaptive or predictive control etc. But all these are prone to increased control complexity and may lead to deprivation of dynamic performance.

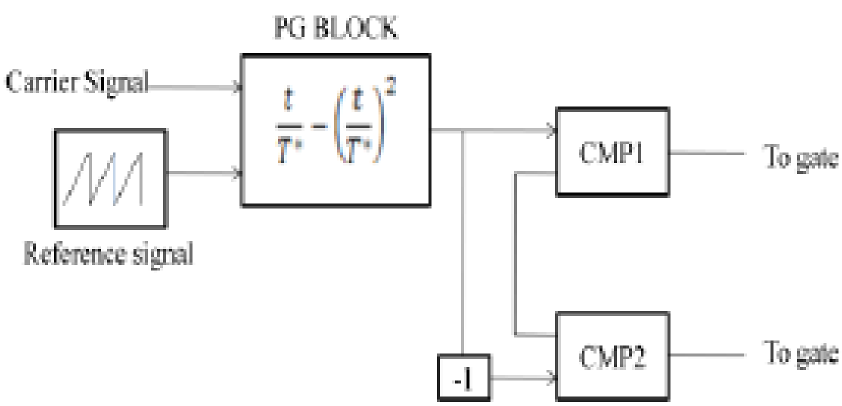
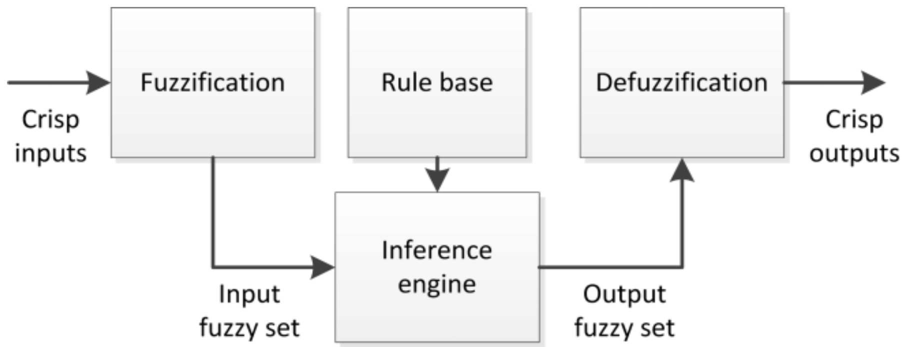


Fig. 2: Parabolic PWM.

III. Fuzzy Logic Controller

The fuzzy controller is made up of four primary parts: The knowledge in the form of a collection of rules outlining the optimal way to manage a system is stored in the rule-base. To measure knowledge, membership functions are being used. The inference system determines which control rules are applicable at this time and then determines which plant input must be activated. The inputs are modified by the fuzzification interface so that they may be understood and matched to the rules in the rule-base. The defuzzification interface converts the plant's inputs into the conclusions derived by the inference engine. A circuit illustration of a fuzzy logic controller is shown in fig. no 3



Fig, 3: Block diagram of a fuzzy logic controller.

A. Description of fuzzy logic tools

Unlike Boolean or crisp logic, fuzzy logic deals with situations that are unclear, uncertain, or imprecise, and employs membership functions with values ranging from 0 to 1. A graphical block diagram of a fuzzy inference system or fuzzy controller is shown in Figure.

It is made up of the following working blocks.

- Fuzzification Interface
- Knowledge base
- Decision making logic
- Defuzzification

A fuzzy controller should have proportional integral control effects because it is a two-dimensional fuzzy control. To get the best performance in a practical situation, an entire action is usually required.

Figure 4 PWM pulse generator

When compared to the PI controller, the Mamdani kind of fuzzy controller used for APF control produces superior results, but it has the disadvantage of having a larger number of fuzzy sets and rules.

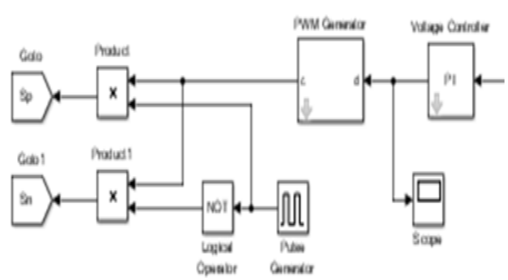


Fig.4: PWM pulse generator.

Furthermore, all of the coefficients must be improved in order to outperform a traditional PI controller. When compared to the PI control system, the fuzzy control takes less time to settle. As a consequence, the results show that for constant power SEIG systems, the fuzzy logic controller-based system outperforms the PI control-based system as a voltage regulator.

IV. Result Analysis & Discussion

Figure 5 showcases the proposed model of single phase grid connected shunt active power filter along with half bridge voltage source inverter containing two MOSFET switches T_1 and T_2. The two clamped capacitor, C1 and C2 on the other leg, acts as a DC bus as well as helps in current compensation. Figure 6 showcases the parabolic PWM controller that undertakes the current control of the SAPF along with source voltage feedback connected to PLL for synchronization of pulses to grid voltage. It provides fast dynamic response and constant source current.

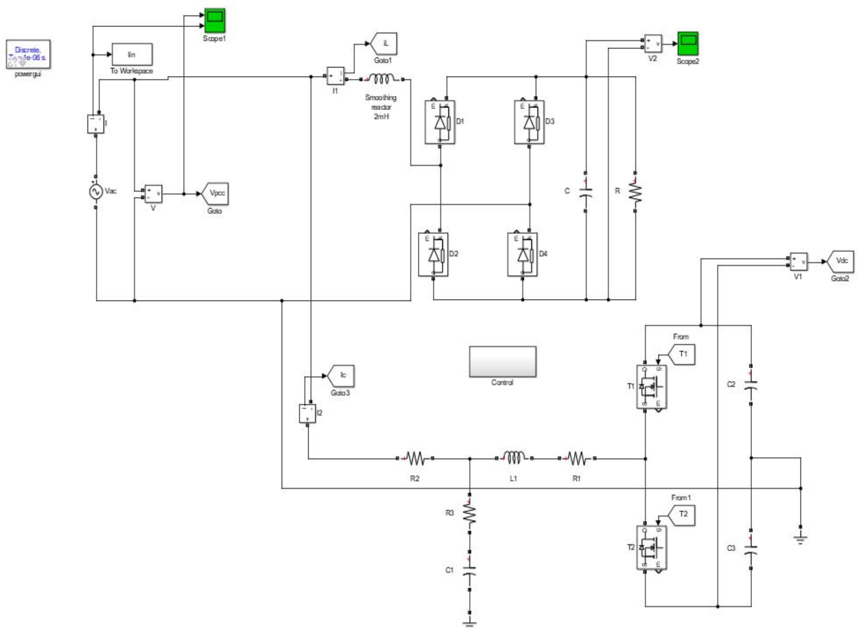


Fig. 5: Proposed test system with single phase active power filter.

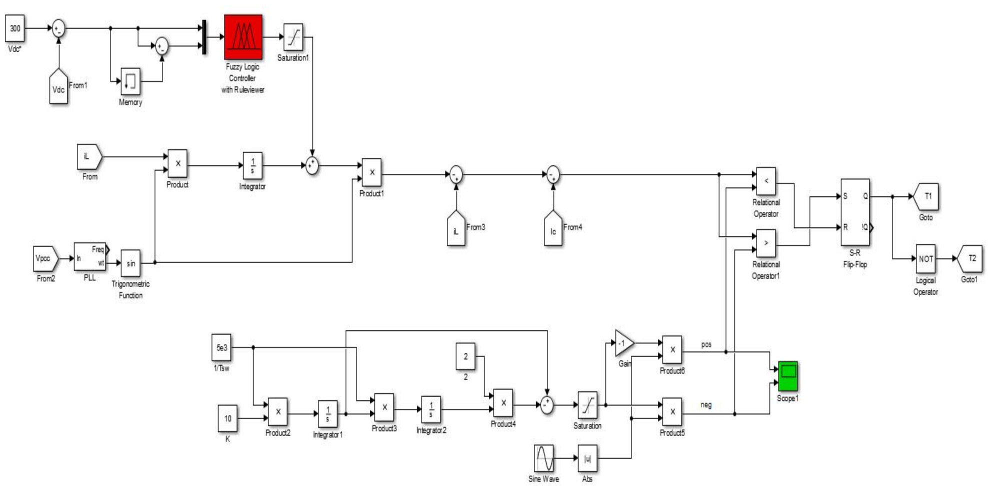


Fig. 6: Parabolic PWM controller of single-phase active power filter with FLC.

The figure 7 showcases the measured source voltage and current before the connection of active power filter.

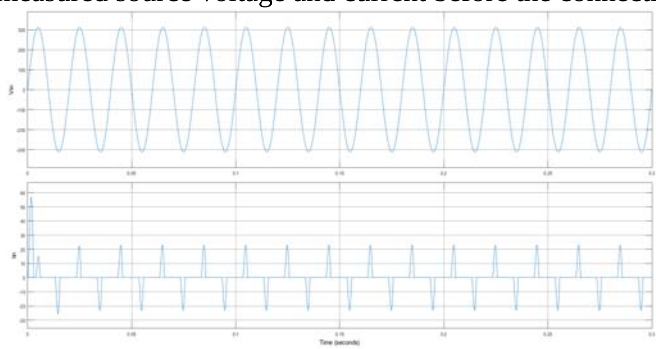


Fig. 7: Source voltage and current.

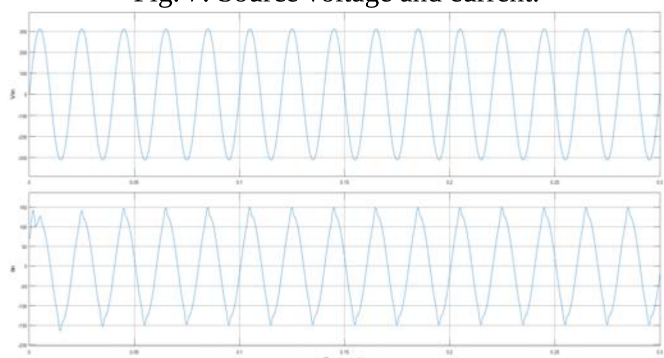


Fig. 8: Source voltage and current.

The figure 9 depicts the DC voltage measured at the load end (nonlinear load) via the diode bridge rectifier. It holds a magnitude of 325V and ripple of 15%.

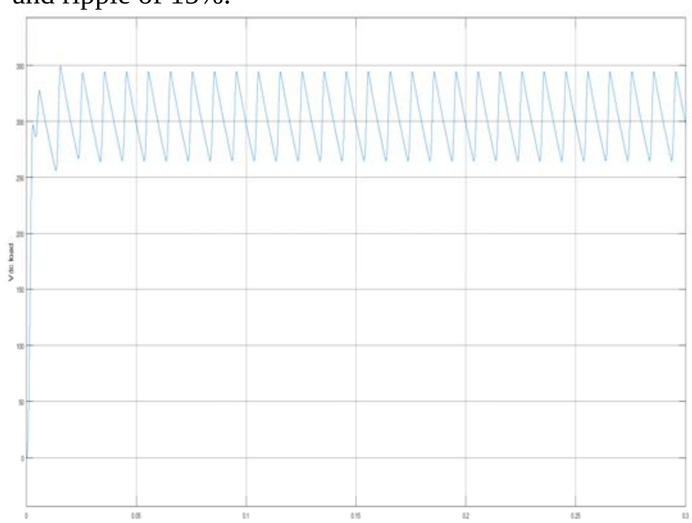


Fig. 9: DC side load voltage.

The FFT analysis of the source current is done determining THD. the below is the THD calculation of source current after connecting active power filter controlled by parabolic PWM technique.

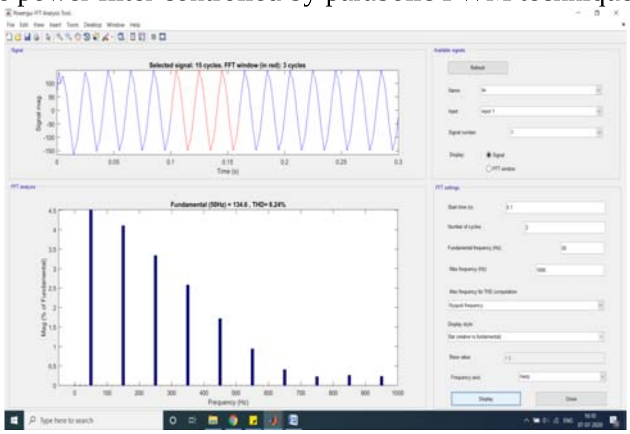


Fig. 10: FFT analysis of source current with parabolic PWM active power filter.

The parabolic PWM technique is replaced with hysteresis PWM controller and the FFT analysis is carried out on source current for the same time and the result is shown below.

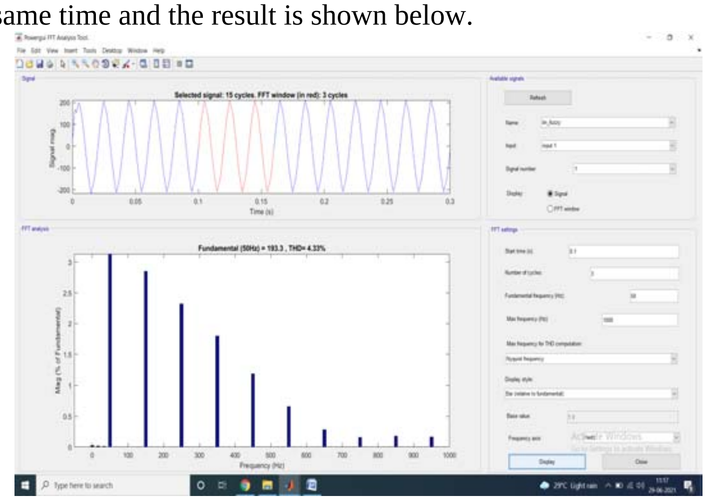


Fig. 11: FFT analysis of source current with fuzzy logic controller.

V. Conclusion

As seen from the above FFT analysis comparison, the source current THD is very high as that of 140% when the non-linear load is feeding from the single phase source. As the active power filter is connected at PCC operated using parabolic PWM technique the FFT analysis of the source current calculates the THD at 6.24%. The THD of the source current is further decreased to 4.33% when the conventional PI controller is replaced with fuzzy logic controller for controlling the MOSFET switches. The active power filter which is connected at PCC helps to mitigate the harmonics generated by the non-linear load. The active power filter compensates the distorted source current signal diverting the harmonics from the non-linear load protecting the source from damage.

References

[1] B. Singh, K. Al-Haddad and A. Chandra, "A review of active filters for power quality improvement," in IEEE Transactions on Industrial Electronics, vol. 46, no. 5, pp. 960-971, Oct. 1999.

[2] T. C. Green and J. H. Marks, "Control techniques for active power filters," in IEE Proceedings - Electric Power Applications, vol. 152, no. 2, pp. 369-381, 4 March 2005

[3] Zhaoyang Yan and Guiping Zhu, "Voltage ripple across the capacitor in DC side of shunt APF," 2012 IEEE International Conference on Power System Technology (POWERCON), Auckland, 2012, pp. 1-6.

[4] T. Thomas, K. Haddad, G. Joos and A. Jaafari, "Design and performance of active power filters," in IEEE Industry Applications Magazine, vol. 4, no. 5, pp. 38-46, Sept.-Oct. 1998.

[5] H. -. Kuo, S. -. Yeh and J. -. Hwang, "Novel analytical model for design and implementation of three-phase active power filter controller," in IEE Proceedings - Electric Power Applications, vol. 148, no. 4, pp. 369-383, July 2001.

[6] N. Mendalek, K. Al-Haddad, F. Fnaiech and L. A. Dessaint, "Nonlinear control technique to enhance dynamic performance of a shunt active power filter," in IEE Proceedings - Electric Power Applications, vol. 150, no. 4, pp. 373-379, 8 July 2003.

[7] Hoon, Y., MohdRadzi, M.A., Hassan, M.K., Mailah, N.F., “Control Algorithms of Shunt Active Power Filter for Harmonics Mitigation: A Review”, Energies, 10, 2038, 2017.

[8] H. -. Jou, J. -. Wu and H. -. Chu, "New single-phase active power filter," in IEE Proceedings - Electric Power Applications, vol. 141, no. 3, pp. 129-134, May 1994.

[9] Wang, G., and Li, Y.W., “Parabolic PWM for Current Control of Voltage-Source Converters (VSCs)”, IEEE Trans. Ind. Appl., vol. 57, no. 10, pp. 3491-3496, 2010.

[10] Y. Singh, I. Hussain, B. Singh, and S. Mishra “Single-Phase Single-Stage Grid Tied Solar PV System with Active Power Filtering Using Power Balance Theory” Received: 9 March 2017 / Accepted: 7 March 2018 the Institution of Engineers (India) 2018.

[11] A. A. Imam, R. Sreerama Kumar, and Y. A. Al-Turki, “Modeling and simulation of a pi controlled shunt active power filter for power quality enhancement based on p-q theory,” Electron., vol. 9, no. 4, 2020, doi: 10.3390/electronics9040637.

[12] R. Kanagavel, I. Vairavasundaram, and S. Padmanaban, “Design and prototyping of single-phase shunt active power filter for harmonics elimination using model predictive current control,” Int. Trans. Electr. Energy Syst., vol. 30, no. 2, pp. 1–21, 2020, doi: 10.1002/2050-7038.12231.

[13] P. Swarnkar, S. K. Jain, and R. K. Nema, “Advanced controlling schemes for active power filter: A review,” Int. J. Emerg. Technol., vol. 10, no. 1, pp. 114–120, 2019.

[14] W. I. S. Qutaina and M. Thesis, “Modeling and C ontrol of Shunt Active Power Filter in Medium Voltage applications,” 2019.

[15] S. S. Managule, S. Dabhole, and S. Gupta, “The shunt active power filter to compensate reactive power and harmonics with optimized PI controller in a 3 phase 3 wire distribution network,” Int. J. Innov. Technol. Explor. Eng., vol. 7, no. 4, pp. 1–7, 2018.

[16] P. K. Ray, “Power Quality Improvement Using VLLMS Based Adaptive Shunt Active Filter,” CPSS Trans. Power Electron. Appl., vol. 3, no. 2, pp. 154–162, 2018, doi: 10.24295/cpsstpea.2018.00015.

[17] Y. Hoon, M. A. M. Radzi, M. K. Hassan, and N. F. Mailah, “Control algorithms of shunt active power filter for harmonics mitigation: A review,” Energies, vol. 10, no. 12, 2017, doi: 10.3390/en10122038.

[18] P. S. Magdum and U. T. Patil, “Development of single phase shunt active power filter,” Proc. Int. Conf. Inven. Commun. Comput. Technol. ICICCT 2017, no. Icicct, pp. 351–355, 2017, doi: 10.1109/ICICCT.2017.7975218.