Active Neutral Point Clamped Inverter Based Grid Connected Active Power Filter

D. Suresh(✉)

Department of Electrical Engineering, National Institute of Technology Raipur, Raipur, India
dsuresh.ee@nitrr.ac.in

Abstract. In this paper, the active neutral point clamped inverter (ANPC) based active power filter (APF) is presented. The APF with instantaneous reactive power theory simultaneously eliminate harmonic current of source and neutral line current caused by load, and feed the active power to the source from photo-voltaic modules. The ANPC based active offer various has the number of advantages including equal distribution of switching losses and small passive filter size than that of neutral point clamped converter (NPC). The instantaneous reactive power theory (IRPT) approach was used to track the APF reference current. To optimise the active power supplied into the grid, the IRPT approach is combined with the MPPT algorithm. The MPPT is realized with incremental conductance method. The reference current is computed with adding the power generated in photo-voltaic reference scheme to the based on IRPT method for consequent computation. The APF is used to cancel out the harmonics and injection of active power caused by photo-voltaic modules. The simulation and real time study of ANPCMLI based grid connected APF using MATLAB/Simulink environments is presented.

Keyword: ANPC · MLI · NPC · APF · IRPT

1 Introduction

The quality of power can be affected by a various factors, including source of power, transmission and distribution systems used to deliver the power, and the characteristics of the loads that consume the power. Some key sources of power quality issues include voltage sags and surges, harmonics, transients, deviation of power factor and voltage unbalance etc. It is important to identify and address power quality issues in order to ensure safe and reliable perofrmance of electrical systems and equipment. This can be done through a variety of measures, including equipment design and selection, system maintenance and monitoring, and the use of power conditioning devices such as voltage regulators, passive harmonic filters, and APF [1–9]. Among the available method for suppression of harmonics, an APF is a versatile device that can be used to enhance power quality of electrical systems by providing harmonic filtering, reactive power compensation, load balancing, voltage regulation, and power factor correction. With a multilevel voltage source inverter or a two level voltage source inverter, the APF can be implemented. The MLI based APF has the advantages of small size filter requirement and

B. Raj et al. (Eds.): ICETE 2023, AER 223, pp. 687–696, 2023.
https://doi.org/10.2991/978-94-6463-252-1_69

allow the higher voltage application without requirement of complex extra circuitry. The ANPC MLI VSI allows the equal distribution losses [10].

The ANPC MLI based APF is adopted in this paper for the cancel out the harmonics current of source and neutral line current caused by load, and active power inject from photo-voltaic modules to grid. The computer simulated response is carried out with MATLAB/Simulink Simpower system block sets library. The simulation characteristics shows that ANPC MLI based APF can compensate the harmonics current and feed the photo-voltaic power to the grid without requirement of the independent VSI based APF.

2 Configuration of APF Topology

The power circuit of three phase four wire (3P4W) ANPC MLI based APF for grid application is shown in Fig. 1. The ANPC MLI based grid connected APF is connected in shunt with load at the point of common coupling (PCC) to mitigate the harmonics current of source and neutral line current, and inject active power of the photo-voltaic modules. The grid connected APF is connected at PCC through coupling inductor. However, the size of the inductor depends on the switching frequency of ANPC MLI based grid connected APF. The PV-panels are coupled on the dc side of ANPC MLI based grid connected APF. The ANPC MLI based grid connected APF is realized with voltage and current estimation for reference current tracking. The MPPT is realized with estimation of the voltage and current of PV-modules. The grid connected APF is used to generate the compensating current and inject it into the grid, while the control system is responsible for detecting the harmonic content and generating the appropriate compensating current. The ANPC MLI based grid-connected APF is a useful tool for improving the quality of power in grid-connected systems, and it has become increasingly important as more renewable energy sources are integrated into the grid (Table 1).

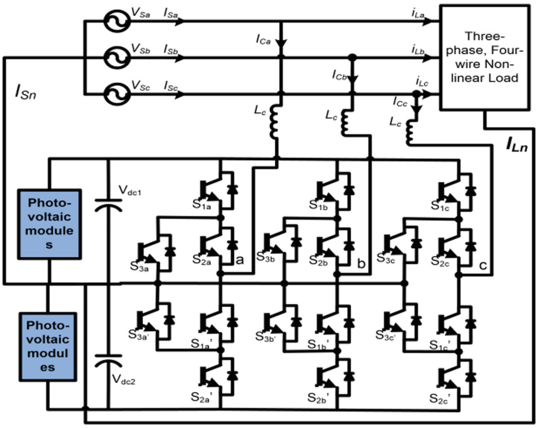


Fig. 1. Topology of PV cell integrated ANPC based-APF.

Table 1. Switching sequence of the ANPC MLI inverter

S_{a1}	S_{a2}	S_{a3}	S_{a4}	S_{a5}	S_{a6}	Output voltage
1	1	0	0	0	1	$V_{dc/2}$
0	1	0	0	1	0	0
0	1	0	1	1	0	0
1	0	1	0	0	1	0
0	0	1	0	0	1	0
0	0	1	1	1	0	$-V_{dc/2}$

3 Control Scheme of APF

The control method ANPC based APF is shown in Fig. 2. The instantaneous reactive power theory is presented by the H. Akagi et al. [11]. The instantaneous reactive power the is time domain based approach and used to compute the real and reactive power using transformed quantitities. İnitially, the three phase quantities are transformed to bi-phase quantities using clark transformation and consequent computation of the real and reactive power. The ANPC based APF is used to compensate harmonics and reactive power caused by the load. The harmonics power is obtained with low pass filter and reactive power sign is reversed so that the ANPC based APF inject opposite the harmonics power and reactive power to the load. İn to this, active power from the PV modules is computed and substracted from the harmonics power of the control method. The maximum power point tracking is obtained using incremental conductance method. The MPPT is used to decide the reference value for the ANPC based APF and inject the active powe to the grid. The IRPT method is not suitable for the three phase four and distorted voltage conditions. The unit voltage vector templates are used for the computation of the voltage in for the computation of the power.

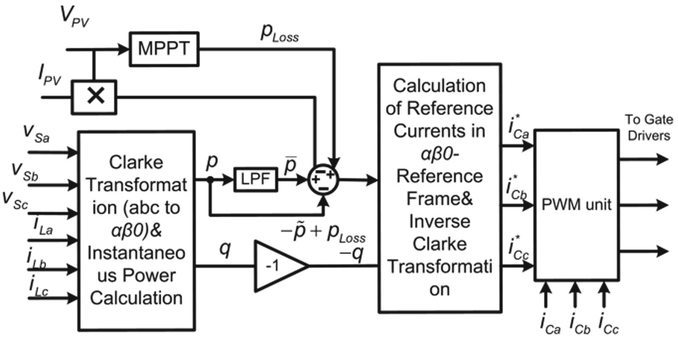


Fig. 2. IRPT method for ANPC MLI based grid connected APF.

4 Dynamics Model of PV Cell

The dynamic model can be expressed mathematically using a set of equations that describe the current-voltage (IV) curve of the PV cell. These equations can be solved numerically to predict the behavior of the PV cell under different operating conditions. The dynamic model of photo-voltaic cell is shown in Fig. 3.

The current source represents the photo-current generated by the PV cell, which is proportional to the incident irradiance. The diode model represents the nonlinear behavior of the PV cell, which includes the effects of temperature and the voltage across the cell. The resistor model represents the series and shunt resistance of the cell, which affects the voltage and current output of the cell and equations which is used to describes its I–V characteristics as follows

$$\begin{aligned} I &= I_L - I_d - I_{sh} \\ &= I_L - I_D\left[e\frac{qV_{oc}}{CkT} - 1\right] - \frac{V_{out} + R_S I}{R_{sh}} \end{aligned} \tag{1}$$

where I_D = Saturation current, charge $q = 1.6 \times 10^{-19}\,C$, C = diode emission factor $k = 1.38 \times 10^{-23}\,J/K$ = Boltzmann constant and T = temperature.

The dynamic model is useful for optimizing the performance of PV systems, as it can help to determine the optimal operating point of the PV cell and the maximum power point (MPP) of the system. It can also be used to design and evaluate the performance of MPPT controllers, which are used to ensure that the PV system operates at its maximum power point under varying conditions. The MPPT is integrated with grid connected APF control method to extract the MPP from the photovoltaic system. The MPPT, which is used for the extraction of MPP can be described by following equations of incremental conductance method [7].

$$\frac{dp_d}{dv_d} = \frac{d(v_d i_d)}{dv_d} = i_d + v_d\frac{di_d}{dv_d} = 0 \tag{2}$$

$$\frac{dv_d}{di_d} = -\frac{i_d}{v_d} \tag{3}$$

$$\begin{cases} \dfrac{dv_d}{di_d} > \dfrac{i_d}{v_d} : \ left \\ \dfrac{dv_d}{di_d} < \dfrac{i_d}{v_d} : \ right \end{cases} \tag{4}$$

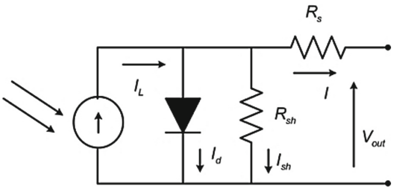


Fig. 3. Equivalent circuit of photovoltaic cell

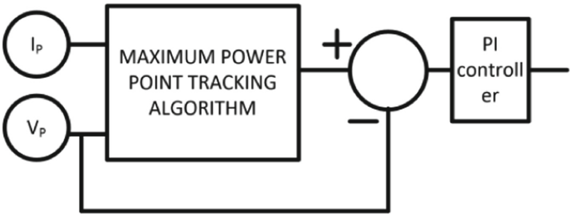


Fig. 4. MPPT for DC voltage regulation

5 DC Link Voltage Regulation

The outer loop used for voltage control with MPPTalgorithm is shown in Fig. 4. The measured value of photo-voltaic voltage and current is used for the estimation of the reference voltage. The estimated voltage with incremental conductance method is used for voltage regulation across the dc link capacitors of the APF. The value of the reference estimated voltage with MPPTis depends on the solar irradiations. Then the estimated voltage is used to decide the active power injected into the grid. The active power injection is carried out with the ANPC APF. In addition to this, the active power estimated with maximum power point algorithm also substrated from the harmonics active power of control scheme. The complete process used for the subsequent computations of the reference currents of the APF.

6 Simulation Results and Discussion

The complete power system blocks of the ANPC MLI based grid connected APF is built using MATLAB/Simulink block sets. The complete system of ANPC MLI based grid connected APF consists of the source block, ANPC MLI VSI, control unit, and nonlinear load. The three sources are realized using MATLAB/Simulink Simpower system source block sets. The control unit of the ANPC MLI based grid connected APF is built with commonly used Simulink library and control blocks of MATLAB/Simulink library. The ANPC MLI based grid connected APF and nonlinear load are modelled with power electronics and elements of library of MATLAB/Simulink. The switching pulses for the ANPC MLI based grid connected APF generated in MATLAB/Simulink environment is shown in Fig. 5.

The simulation study carried out for ANPC MLI based grid connected APF by the MATLAB/Simulink is depicted in the Fig. 6. The simulated waveforms of the grid-APF without PV-panel on its dc link are shows the harmonics elimination capability. After grid-APF is switched-on at t = 0.05 s, the grid-APF eliminates the harmonics current of the load. The load current total harmonics distortion from the waveform found to be 13.8%. While grid-APF acting alone without the PV-panels on dc capacitor side is used to eliminate the current harmonics present in the grid current. The source current waveform is tends to sinusoidal from the triplen harmonics waveform. The grid current THD distortion after elimination of harmonics found to be 3.34%. The source current waveforms after mitigation harmonics current with APF found to be improved and can

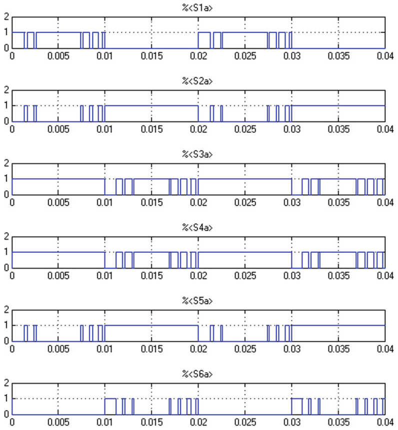


Fig. 5. Switching pulse generation

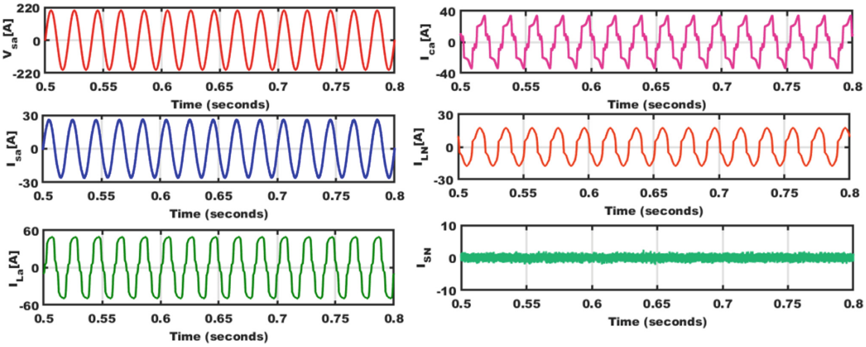


Fig. 6. Simulated waveform of ANPC MLI based grid connected APF.

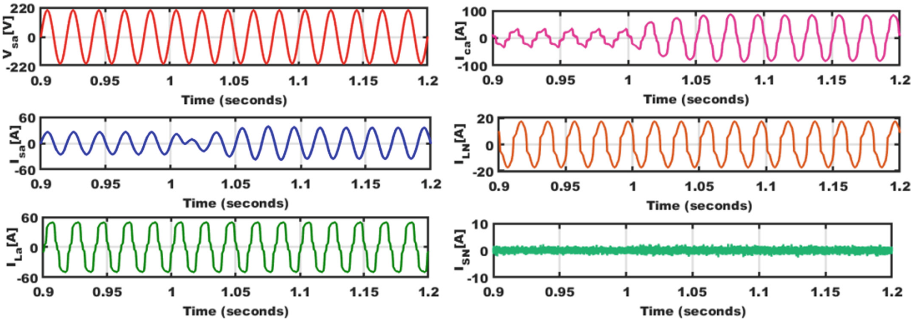


Fig. 7. ANPC MLI based APF Simulated waveform with MPPT.

be observed from the waveforms. The neutral line current also eliminated with ANPC MLI based APF.

The simulated response of the ANPC MLI based grid connected APF is depicted in Fig. 7. It can be observed from waveforms of Fig. 6, before, harmonics currents mitigation with ANPC MLI based APF, and source current follows the load current. After harmonics currents cancel out with APF, source current is in phase with source voltage and waveform of source current is nearly sinusoidal as it can be seen from the Fig. 6. As it can observed from the Fig. 7. The MPPT of the ANPC MLI based grid connected APF is integrated with the control method so that the active power from the PV-modules pumped to the source via coupling inductor. The source current of ANPC MLI based grid connected APF is used flow in reverse direction and it can be seen from Fig. 7. As the solar irradiation increases, the active power extraction from the PV-panel is increased and subsequently increases of the source current (Fig. 8).

The APF simulated response of the APF under power variation can be seen from the Fig. 7. The simulated waveforms obtained from the APF are identified as PV-voltage, PV-current and corresponding active power computed from voltage and current. The simulated PV-voltage and dc link capacitor voltages are same. The dc link voltage of the APF is control in such way that active power from PV-panel can be injected at the point of common coupling. In addition to this, the active power computed from the PV-panel is substrated from the oscillating power computed from the voltage and load current. The power variation can be observed from the waveform and its value depends on the solar irradiations. As the active power generated from the solar panel increases that leads to corresponding increase in the active power pumped on to the grid. This variation in current of APF can be observed from the Fig. 6. From the waveforms, it can be observed that the gradual increase in the source current with respect to the APF current. The increase in source current shows that the corresponding burden caused load current reduced. The total harmonics distortion of source current without compensation with

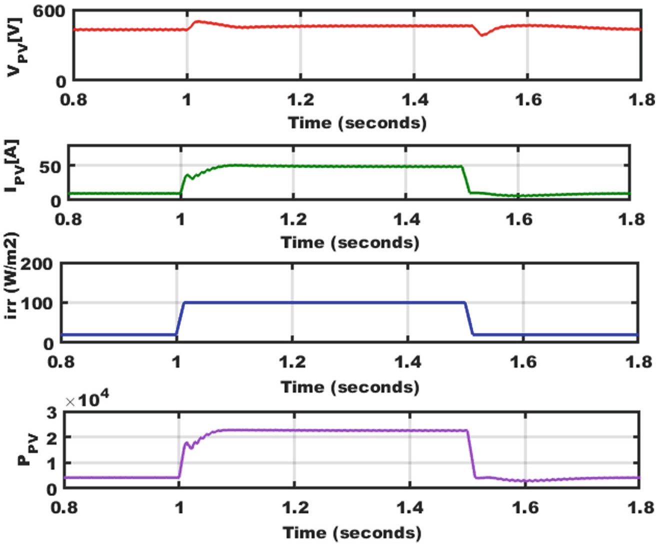
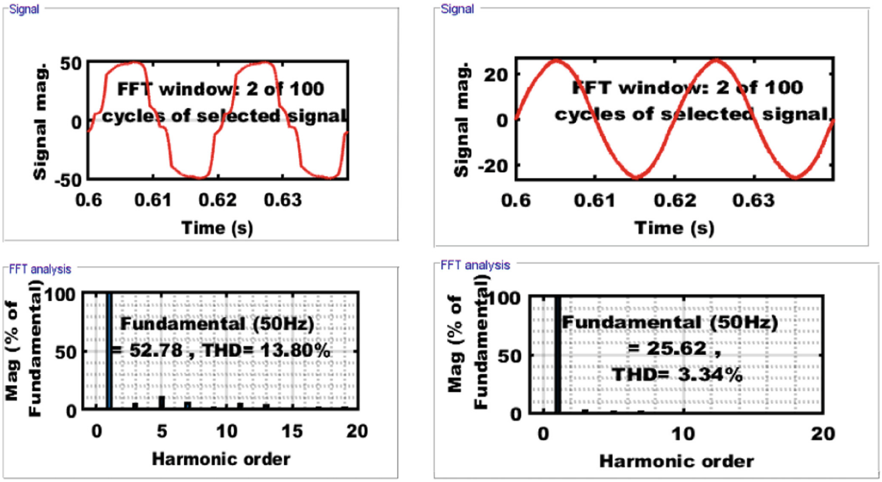


Fig. 8. Simulated waveform with power variation.



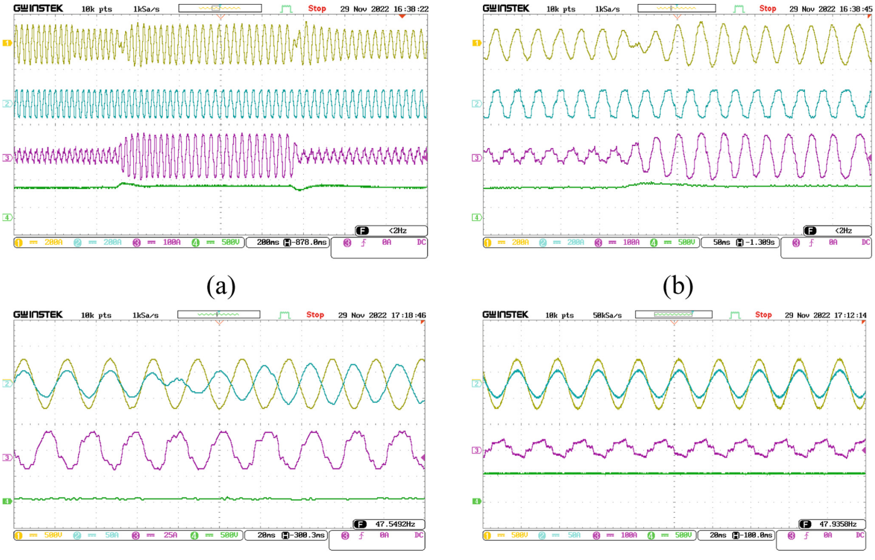
(a) Source current THD without APF (b) Source current with APF

Fig. 9. Source current with APF. (a) Source current THD without APF. (b) Source current with APF

ANPC MLI based grid connected is found to be 23.72%. After compensation with APF source current THD is found to be 2% and can be seen from Figs. 9 and 10 respectively.

7 Real Time Validation of ANPC Based APF

Figure 10 depicts the real-time study of the grid-connected APF that is based on ANPC. Figure 10(a) and (b) illustrate the source phase current, load side current, ANPC based APF current, and dc side voltage, respectively. During the grid connected operation, the ANPC APF is used to inject the current to the grid with increase solar irradiation level. The source phase voltage, source phase current load neutral line currents and source neutral line current after suppression with ANPC APF is shown Fig. 10(c) respectively. Before the availability PV power source current is sinusoidal in phase with source voltage. After the injection of active power with grid connected APF, source phase is in phase opposition to the grid voltage. The load neutral current remains unchaged and source neutral line current is suppressed. The ANPC based APF without PV source is shown in Fig. 10(d). The without PV source, the ANPC based APF is used cancel out the harmonics current and reactive power caused by the load.



(a) (b)

(c) (d)

Fig. 10. Real time study of the ANPC based DSTATCOM

8 Conclusion

In this project, photovoltaic inverter based on ANPC is used as the APF. The photovoltaic APF is used to eliminate harmonics of source current and suppress neutral line current, and carryout active power injection from the photovoltaic system to the grid. The PV-APF does not require the separate inverter power circuit to for compensation of harmonics currents and reactive power requirement of load. The reference current estimation PV-APF is carried out with IRPT method. The MPPT method is implemented based on incremental conductance method. The MPPT algorithm is in combined with IRPT method to track the active power and compensates harmonics currents of the load. The active power computed from the PV-modules is used to regulate the dc side voltage of the APF. The reference dc link voltage changes corresponding change in active power injected to the grid are observed. The ANPC MLI based APF shows the promising results for simultaneous compensation of harmonics and active power injection without requirement of separate ANPC-APF.

Acknowledgements. Thank to National İnstitute of Technology Raipur for seed grant project (NITRR/Seed grant/2021–22/44).

References

1. Singh, A. Chandra and K. Al-Haddad, "A review of active filters for power quality improvement", IEEE Transactions on Industrial Electronics, vol. 46, no. 5, p. 112, Oct 1999.
2. Y. Komatsu, "Application of the extension pq theory to a mains-coupled photovoltaic system", Proc. Power Convers. Conf. (PCC), vol. 2, pp. 816–821, 2002.
3. D. Casadei, G. Grandi and C. Rossi, "Single-phase single-stage photovoltaic generation system based on a ripple correlation control maximum power point tracking," in *IEEE Transactions on Energy Conversion*, vol. 21, no. 2, pp. 562–568, June 2006, doi: https://doi.org/10.1109/TEC.2005.853784.
4. N. Palla and V. S. S. Kumar, "Coordinated Control of PV-Ultracapacitor System for Enhanced Operation Under Variable Solar Irradiance and Short-Term Voltage Dips," in *IEEE Access*, vol. 8, pp. 211809–211819, 2020, doi: https://doi.org/10.1109/ACCESS.2020.3040058.
5. Suresh, D., Kumar, V., Mahesh, M. (2022). Twelve Pulse-Based Battery Charger with PV Power Integration. In: Marati, N., Bhoi, A.K., De Albuquerque, V.H.C., Kalam, A. (eds) AI Enabled IoT for Electrification and Connected Transportation. Transactions on Computer Systems and Networks. Springer, Singapore. https://doi.org/10.1007/978-981-19-2184-1_9.
6. M. Liang, et al., "Modeling and control of 100 kW three-phase gridconnected photovoltaic inverter," in 2010 5th IEEE Conference on industrial Electronics and Applications (ICIEA 2010), pp. 825–30 Jun 2010.
7. Issam Houssamo, Fabrice Locment, Manuela Sechilariu, "Experimental analysis of impact of MPPT methods on energy efficiency for photovoltaic power systems," International Journal of Electrical Power & Energy Systems, Vol. 46, pp. 98–107, 2013.
8. Bhim Singh and J. Solanki, "Load Compensation for Diesel Generator-Based Isolated Generation System Employing DSTATCOM", *IEEE Trans. on Indu. Appl*, vol. 47, no. 1, 2011.
9. H. Xu, A. Bubert, M. Laumen and R. W. De Doncker, "Active Neutral-Point Balancing of Three-Level Neutral-Point-Clamped Traction Inverters," *2018 21st International Conference on Electrical Machines and Systems (ICEMS)*, Jeju, Korea (South), 2018, pp. 2256–2261, doi: https://doi.org/10.23919/ICEMS.2018.8549060.
10. T. Bruckner, S. Bernet and H. Guldner, "The active NPC converter and its loss-balancing control," in *IEEE Transactions on Industrial Electronics*, vol. 52, no. 3, pp. 855–868, June 2005, doi: https://doi.org/10.1109/TIE.2005.847586.
11. Hirofumi Akagi; Edson Hirokazu Watanabe; Mauricio Aredes, "Shunt Active Filters," in *Instantaneous Power Theory and Applications to Power Conditioning* , IEEE, 2017, pp. 111–236, doi: https://doi.org/10.1002/9781119307181.ch4.