

*The wide spectrum of electromagnetism that explains current and voltage at specific time and location in a power system is referred to as power quality. Alternative energies are becoming more popular due to concerns about power quality, safety, and the environment, as well as commercial incentives. Moreover, photovoltaic (PV) energy is one of the most well-known renewable resources since it is free to gather, unlimited, and considerably cleaner. Active power filter (APF) is an effective means to dynamically suppress harmonics and solve power quality problems caused by the DC side voltage fluctuation. Therefore, this paper describes a substantial advancement in the harmonic suppression compensation algorithm, as well as the cascaded active power filter. Also, this paper focuses on compensating the error of photovoltaic grid-connected generation based on optimized H-bridge cascaded APF. The details of the working principle and topological structure of the APF used as the compensation device are analyzed. The H-bridge cascaded APF is optimized using the segmented variable step-length conductance increment (SVSLCI) algorithm. The overall cascaded APF control strategy is designed and simulated using MatLab/Simulink environment. By the simulation results comparing the existing traction network power quality control measures, before and after compensation, the effectiveness of the proposed control strategy is verified. The proposed controller strengthens the compensation of specific odd harmonics to improve the system work models and criteria to improve power quality. Moreover, the proposed algorithm showed positive significance for optimizing the quality of photovoltaic grid-connected power, reducing the current harmonic, and improving the equipment utilization of photovoltaic inverters*

**Keywords:** active power filter, photovoltaic grid-connected, DC link capacitor, control strategy, harmonic compensation, cascaded multilevel

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# HARMONIC SUPPRESSION COMPENSATION OF PHOTOVOLTAIC GENERATION USING CASCADED ACTIVE POWER FILTER

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## 1. Introduction

Traditional fuel energy is an important material basis for human survival and development. With the increasingly serious energy crisis and air pollution, solar energy has become one of the most promising new energy sources at home and abroad with its richest and cleanest characteristics [1]. Due to the cloudy and sunny weather and the alternation of day and night, photovoltaic power generation has the problems of intermittent, non-linear, and low inverter capacity utilization efficiency [2]. As traction loads and power electronic equipment are heavily invested in the grid, a series of power quality problems such as harmonic pollution, power factor reduction, and voltage fluctuations have been caused. With the increase in the application of distributed photovoltaic sources in the electrical grid, how to use the remaining capacity of the inverter to manage the power quality problem has become a hot research topic at home and abroad [3, 4]. In the current study, the installation of solar source such as PV with APF is a promising path of exploration. By having an alternate power source rather than relying on the power

source from the supply network, this integration gives substantial benefits. APF can work with probable dynamic variations in injection current because PV is fully dependent on solar irradiance. As a result, the injection current should always be carefully managed with a specific end objective in mind to ensure the APF's ability to compensate current harmonics [5]. The existing algorithm methods for harmonics extraction can be divided into three categories. Artificial intelligence, time domain, and frequency domain approaches are among them. The frequency analysis is always connected with Fourier factor computation and sampling time, which makes any techniques in this domain challenging to utilize in real-time applications, especially with constantly variable demands [6]. When compared to the frequency domain, the time domain performs better in terms of fast convergence. However, there are probable indicators of existing noise induced by the translation of the coordinates from the incoming signal [7], thus it remains speculative. It can extract basic components that vary over time in terms of phase angle and magnitude to reduce harmonic elements [8].

Many researchers introduced a large number of power electronic components in photovoltaic inverters, which will inevitably generate harmonics during the inverter process and cause harmonic pollution to the grid [9]. However, additional enhancements are required due to the algorithm's remaining unneeded qualities. They do not fulfill the fundamental criterion of extracting harmonics [10]. Because of the sluggish learning rate and the possibility of a big average square error, these superfluous qualities have an impact on the application's performance. These two things are due to the updating method's learning value and the cosine element, which may alter the algorithm's response time. As a result, lag compensation is still in use [8]. This algorithm has a total harmonic distortion (THD) of less than 5% with an action time of 40 ms. Problems like high THD and capacitor failure may develop as a result of the unstable injection current, contributing to the significant drawbacks [9]. As a result, self-charging methods have seen a considerable growth in popularity as an alternative to the traditional method or algorithm [11]. The active filter (APF) is a voltage-type full-bridge structure completely consistent with the main circuit of the grid-connected inverter in the three-phase photovoltaic grid-connected power generation system [5]. APF is a new approach of power electronic component that harmonics are efficiently repressed [2]. Here, the APF of the cascaded H-bridge multilevel topology is used as the active compensation device of the traction network [3]. Current harmonics are generally caused by the nonlinear load actions of power electronic devices. Another cause is when components that are introduced later in the process are injected into the power system. These issues arise as a result of the involvement of several sources in the power system, as well as the inclusion of a photovoltaic (PV) grid-connected system. Therefore, the main message is to explain a significant breakthrough in the harmonic suppression compensation method and the cascaded active power filter based on optimized H-bridge cascaded APF.

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## 2. Literature review and problem statement

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In the literature, there are several studies focused on APF. Among them, [6] proposed a unified control strategy based on photovoltaic and active filtering, which integrates power transmission and power quality management. The paper [7] successfully presents a decrease in the harmonic components of photovoltaic and improvement of the power factor, but they are not in the synthesis of grid-connected command current, the capacity of the inverter is taken into consideration, and only a single change experiment of a single variable of light or load is performed, and the unified control effect of the system in continuous environment and load changes has not been compared and verified. The power conversion law [8] is primarily used to govern the charging and discharging of the DC capacitors. As a result, it provides excellent accuracy and controlled voltage that is clean and noise-free. Previously [9], this voltage problem was managed using algorithms such as fuzzy logic approaches. These strategies were designed to process the input value without previous understanding of its behavior. As a result, regardless of whether the voltage error varies or not, it must still be regulated and treated [12]. Self-charging and variable

step error cancellation, an indirect solution incorporating fuzzy control approaches, was introduced in [13]. This indirect method creates improved performance with minimal overshoot and undershoot but it is only relevant for shunt active power filter systems and no testing is performed for PV APF, mainly under different irradiance levels. The paper [14] considers the order and magnitude of harmonic suppression and reactive power compensation, and it has certain reference to determine the grid-connected command current synthesis scheme, but the 16 different harmonics and reactive power compensation situations of its design are very complicated. It has not studied the oscillation of photovoltaic cell output current. The network command current synthesis link affects the accuracy of harmonic compensation and has an impact on the harmonic control of the system. In order to solve the above problems, this paper is based on a unified control strategy that combines the triple functions of photovoltaic grid-connected, harmonic suppression and reactive power compensation, and improves the segmented variable-step conductance increment method, focusing on eliminating photovoltaic cell output current oscillations for harmonic compensation. However, these problems still affect the healthy operation of the traction power supply system, and also cause many disadvantages to other related equipment involved in the system, so effective measures must be taken to eliminate them. In [15], the modelling of the harmonics of grid system PV is presented. In addition, the study was based on the synchronous reference frame and PI controllers to make control and compensation system. Because standard electric power networks are being challenged by increased power demand, limited power delivery capabilities, difficulties in establishing transmission lines, and shortages, distributed components with static inverters are being used and targeted more [16]. Previously, methods such as proportional-integral (PI) and fuzzy logic techniques were used to control voltage error. Both procedures were set up. To process the incoming value directly without first knowing its behaviour [17].

The brief introduction of photovoltaic grid-connected generation and the topology of the cascaded H-bridge APF. The optimized current tracking control technology and DC side voltage equalization control using the segmented variable step-length conductance increment method. Therefore, it is proposed to use an optimized H-bridge cascaded APF to compensate the photovoltaic grid-connected generating error. The MatLab/Simulink simulation platform, a simulation model of cascaded APF is built; it is verified that cascaded APF is an effective method of harmonic control. Despite the fact that many researchers have been devoted for many years to the power quality in a power system and the problem of current harmonics created by various energy source systems, there are still some difficulties with reducing such harmonics impacts. Therefore, this paper also optimizes the basis for determining the inverter capacity, and designs a reasonable working mode according to the lighting conditions and non-linear load changes.

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## 3. The aim and objectives of the study

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The study's aim is to compensate the error of photovoltaic grid-connected generation based on optimized H-bridge cascaded APF.

To achieve this aim, the following objectives are accomplished:

- to support and evaluate the proposed approach, the MatLab/Simulink simulation platform, and simulation model of cascaded APF was considered to verify that cascaded APF is an effective method of harmonic control;
- to use the segmented variable step-length conductance increment method for optimized current tracking technology and DC side voltage equalization control.

4. Research materials and methods

4.1. Photovoltaic grid-connected and active filter

The structure the overall circuit of the photovoltaic system combined with active filtering function is mainly composed of photovoltaic cells PV, DC-DC boost chopper circuit, three-phase full-bridge inverter and traditional disturbance and observation Adaptive Perturb and Observe (P&O) method, maximum power tracking module, harmonics and Reactive current detection module, command current synthesis and work mode determination module, as shown in Fig. 1. Due to its high precision and quick response time for controlling the steady-state error of the reference current signal, the current control algorithm proportional-integral (PI) was applied [18].

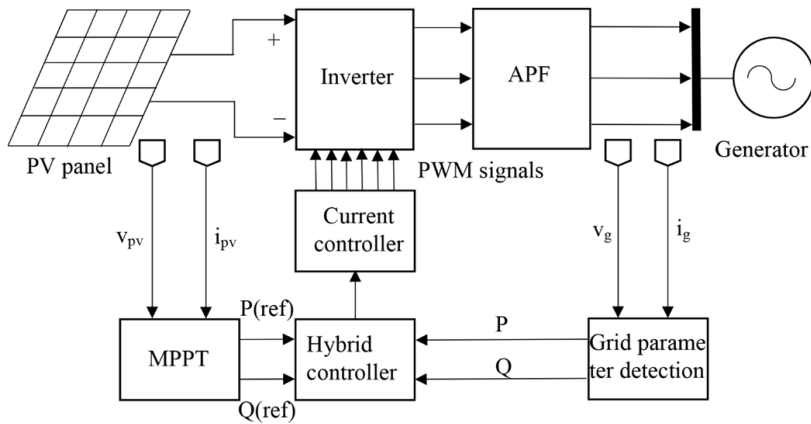


Fig. 1. Photovoltaic grid-connected and active filter

During the day, there is sufficient sunlight, the photovoltaic cell generates the maximum power, the system limits harmonic compensation according to the capacity. When the sunlight is insufficient, such as cloudy days, it improves harmonic reduction and compensation. At night, the system works in APF-only mode to improve equipment utilization [19].

4.2. Cascaded H-bridge type APF

Fig. 2 shows the working principle of the cascaded H-bridge type APF, which includes a circuit equivalent resistance R, an equivalent reactance L and multiple H-bridge modules. A single H-bridge module contains 4 fully-controlled power electronic devices, mainly IGBTs and DC side

capacitors. The function of the DC side capacitor is to store and convert energy, stabilize the voltage, and also have a certain filtering function. Connect N H-bridge modules together to form a single-phase cascaded H-bridge multilevel converter [20].

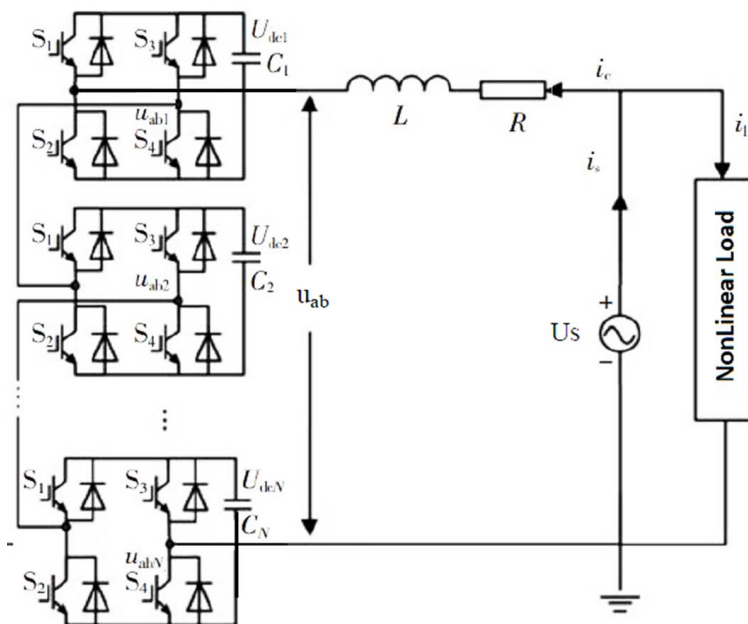


Fig. 2. The circuit of cascaded H-bridge APF

First, the traction network voltage and the current of the nonlinear load can be detected by the system, and then the voltage output from the AC side of the cascaded H-bridge APF and the traction bus voltage act together on the grid-connected reactor, and the output is the same as the command current amplitude. Compensation currents with opposite phases are injected into the traction network to achieve the purpose of offsetting reactive power and harmonics. The load current  $i_L$  can be equivalent to the parallel form of fundamental active current  $i_{Lp}$ , reactive current  $i_{Lq}$ , and harmonic current  $i_{L,h}$ , as follows [21]:

$$i_L = i_{Lp} + i_{Lq} + i_{L,h}. \tag{1}$$

Traction network current is

$$i_s = i_L + i_{Lc}. \tag{2}$$

To compensate for harmonics and reactive currents, only:

$$i_c = -(i_{Lq} + i_{L,h}). \tag{3}$$

Fig. 2, suppose the traction network voltage  $u_s$  is an ideal sine, as follows

$$u_s(t) = U_{s,m} \sin \omega t, \tag{4}$$

where  $U_{s,m}$  is the peak value of the traction network voltage;  $\omega$  is the angular frequency of the fundamental voltage.

The equivalent resistance ignored of the grid-connected inductance, Kirchoff's law can be obtained

$$L \frac{di_c}{dt} = u_s - u_{ab}, \quad (5)$$

$$C \frac{du_{dci}}{dt} = S_i i_c, \quad (6)$$

where

$$S_i = \begin{cases} 1, & u_{abi} = U_{dci}, \\ 0, & u_{abi} = 0, \\ -1, & u_{abi} = -U_{dci}, \end{cases} \quad (7)$$

$$u_{ab} = \sum_{i=1}^N U_{ahi} = \sum_{i=1}^N S_i U_{dci},$$

where  $S_i$  is the switching function of the  $i$ -th power unit. The instantaneous voltage on the AC side of the cascaded APF is the sum of the output voltages on the AC side of each power unit, which can be represented by  $u_{ab}$  as follows.

#### 4.3. DC voltage regulator control

The basic principle of DC side voltage stabilization control is to sum the DC unit capacitor voltage of each power device, calculate the average value  $U_{adc}$ , and then compare it with the difference of the DC unit reference voltage  $U_{dc}^*$ , and use the difference as the PI controller input signal. After the traction bus voltage is synchronized by the phase-locked loop, it is multiplied by the difference between the average voltage setting value adjusted by the PI controller and the actual value, as the current inner loop active current setting value  $i_p^*$ . When the average voltage on the DC side is less than the reference voltage, PI control increases the fundamental wave current, and APF absorbs energy from the traction network side to increase the DC side voltage; conversely, PI controls the fundamental wave current to decrease, and APF releases energy to the traction network. Make the DC side voltage drop. Combine  $i_p^*$  and the extracted command current superposition, as the cascaded APF reference current  $i_c^*$ , generates a cascaded APF modulation signal through the current inner loop.

When APF is working, and under the influence of harmonic currents, the DC side voltage will fluctuate, and then the performance of the APF will decrease, and the compensation effect will be poor due to the loss of power devices [5]. Therefore, it is required to ensure the stability of the DC unit voltage. The DC side voltage regulation control is to equate the DC unit voltage of each power module of the cascaded APF into a whole, and then use the average DC side voltage of each power unit as the control target to keep the cascaded total DC voltage constant APF unchanged. The specific odd harmonic enhancement component  $i_{LSC}$  is superimposed with the harmonic compensation signal  $i_{Lhc}$  and the reactive power compensation signal  $i_{Lqc}$  to generate the compensation current

$$i_{Lqs} = i_{Lhc} + i_{Lqc} + i_{Lsc}, \quad (8)$$

where the photovoltaic active fundamental wave signals  $i_{pv}$  and  $i_{hqs}$  synthesize the grid-connected command current  $i_c^*$  in the rotating coordinate system. The adjustment of the illumination changes  $i_{pv}$ , which will also be reflect-

ed in the waveforms of the inverter output and grid-unit current.

$$i_c^* = i_{pv} + i_{hqs}. \quad (9)$$

Fig. 3 shows the night system control strategy compares the actual DC side voltage  $U_{dc}$  with the set voltage  $U_{dc}^*$ , the voltage difference  $\Delta U_{dc}$  is adjusted by the PI controller to get  $\Delta I_{dc}$ , and finally  $\Delta I_{dc}$  is compared with the compensation current  $i_{hqs}$  synthesized, and the current tracking control is used to generate a PWM signal to keep the stability of the DC side voltage.

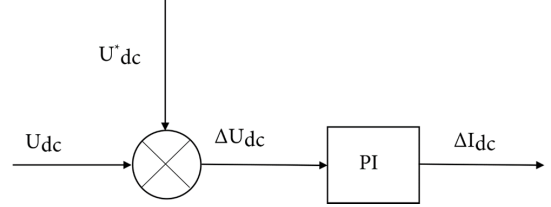


Fig. 3. DC side voltage controller

#### 4.4. Proposed method

The overall control of the cascaded APF system is presented in Fig. 4, which depicts a two-part model. It depicts the instruction current detection and compensation current circuits. The purpose of the command current detection circuit, also known as the harmonic and reactive power detection circuit, is to detect the harmonic and reactive components in the load current.

Moreover, Fig. 5, the tangent function approach with different step magnitude used to optimize the iteration step size is determined by the improved hyperbolic tangent function and the S function. By setting a critical error value, set  $e_0=5$  here. When the absolute value of the actual error is greater than or equal to  $e_0$ , that is, the distance from the steady state is far away, the S function with a large step size can be used to participate in the iterative process; if the actual error is an absolute value. In order to ensure the stability of the multi-function variable step size algorithm, the step size  $\mu$  needs to be restricted in the iterative process, as follows

$$\mu(n) = \begin{cases} \mu_{\max}, & \mu(n) \geq \mu_{\max}, \\ \mu(n), & \mu_{\min} < \mu(n) < \mu_{\max}, \\ \mu_{\min}, & \mu(n) \leq \mu_{\min}, \end{cases} \quad (10)$$

where  $\mu_{\max}$  is usually approximately equal to the steady-state critical value of the traditional fixed-step least mean square (LMS) algorithm to ensure the convergence speed; generally,  $\mu_{\min}$  is a small positive number to ensure steady-state accuracy. Slow down the speed of convergence.

In order to further improve the convergence of the segmented variable step-length conductance increment algorithm (SVSLCI), a new weight momentum is introduced. The change is adjusted by a dynamic factor  $\delta$ , and  $0 < \delta < 1$ . Its iterative formula is

$$w(n+1) = w(n) + 2\mu(n)e(n)x(n) + \delta[w(n) - w(n-1)], \quad (11)$$

where  $w(n)$  is the weight vector;  $e(n)$  is the output error.

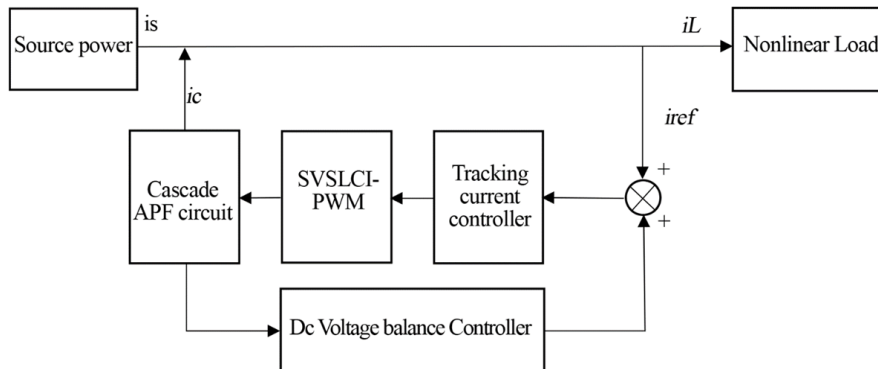


Fig. 4. The proposed cascaded APF control block diagram

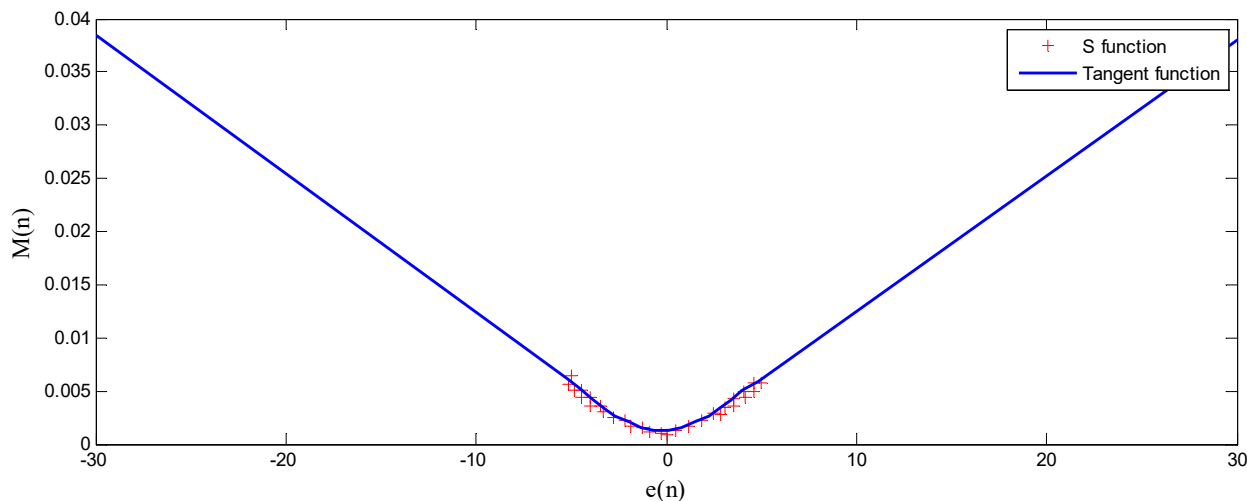


Fig. 5. Variable step function conversion

**5. Research results of compensating the error of photovoltaic grid-connected generation based on optimized H-bridge cascaded APF**

**5. 1. Simulation of photovoltaic grid**

The simulations were carried out using Matlab-Simulink. The proposed PV and APF was designed and linked to a nonlinear load and a grid generator supply source. All of the methods in Fig. 1 were implemented using Matlab-Simulink.

The voltage regulation control requires the average value of the DC side capacitor voltage to be stabilized at 2200 V. After adding the voltage stabilization control, the average waveform of the DC voltage of each sub-module is shown in Fig. 6.

The graph shows that the average value of the DC side voltage is essentially stable at 2,200 V, which meets the basic requirements of voltage control, and the fluctuation error of the steady-state voltage is approximately, which can ensure the normal operation of the cascaded APF.

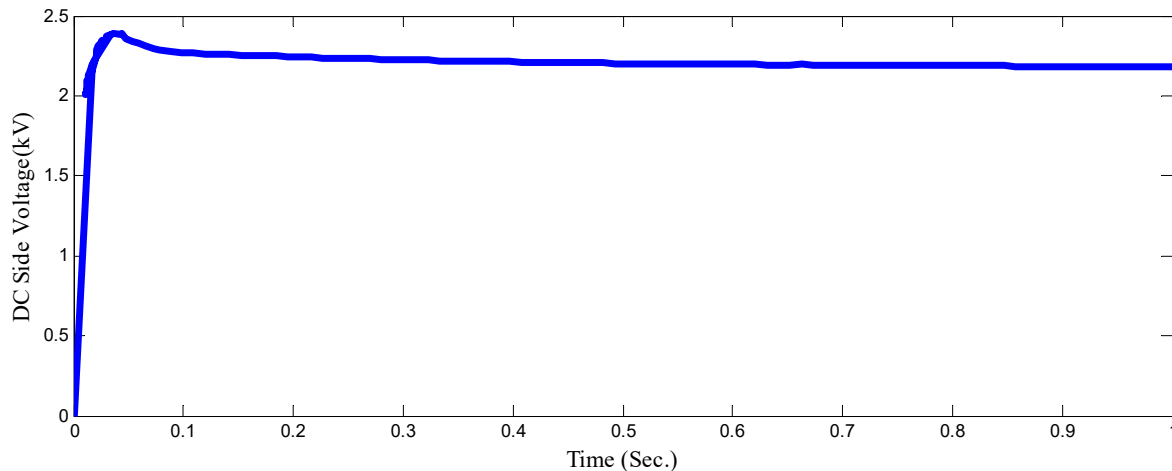


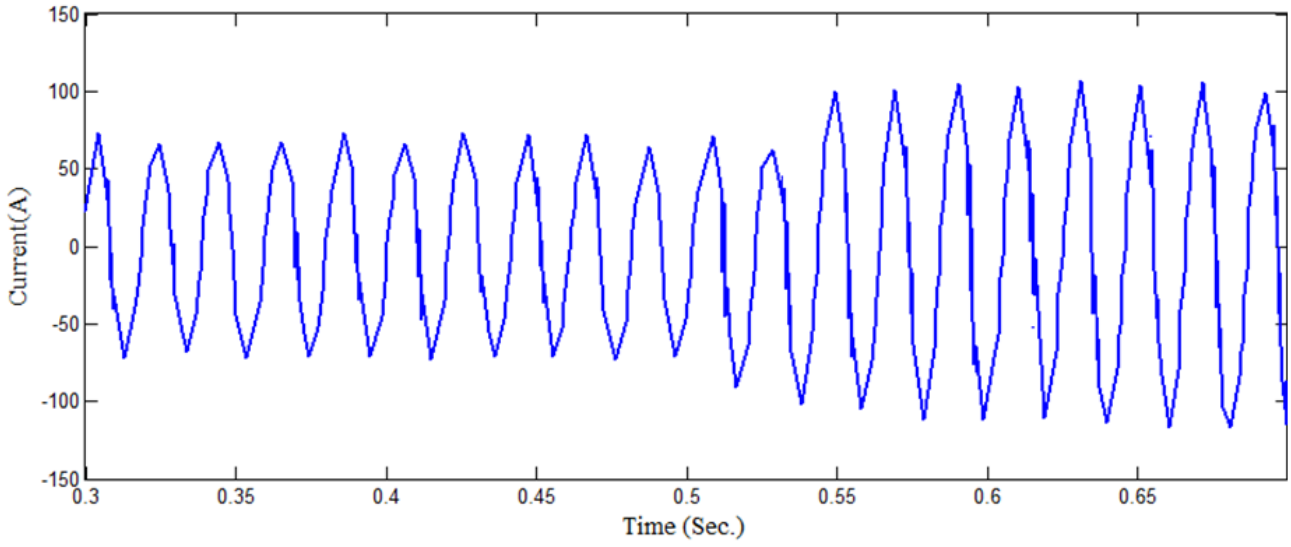
Fig. 6. DC side voltage regulation control

**5. 2. Current control methods**

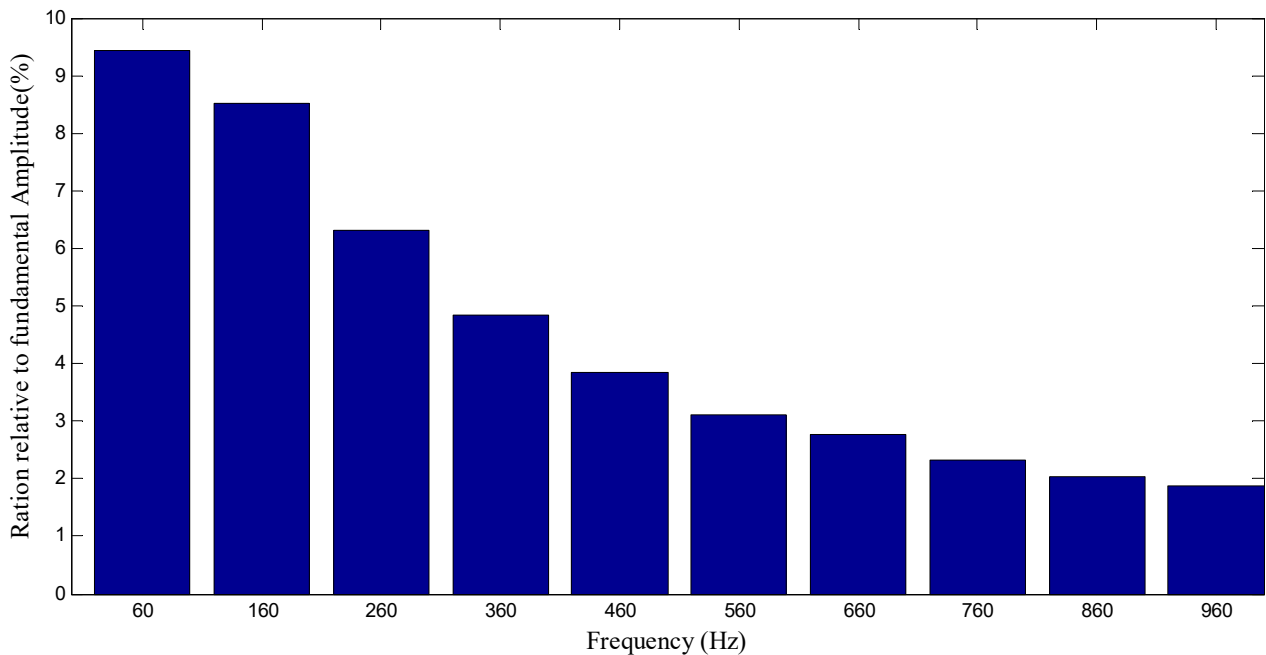
In order to verify the effectiveness of deadbeat current control, suppose a 0.5 s abrupt load, its load current and FFT spectrum analysis are shown in Fig. 7, 8. It can be seen from the simulation results that after a sudden load change, after about 2 power frequency cycles, the compensated grid-side current is stable. It can be seen from the current tracking simulation results that the deadbeat current control can track the change of the reference command current almost in real time, has good steady-state accuracy, and greatly reduces the harmonic content of the grid-side

current. Fig. 4, 6 introduce other current control methods after comparison, it is found that the deadbeat current control phase after hysteresis compensation and current correction has significantly improved compensation accuracy.

Indeed, Fig. 8 depicts the effectiveness of both DC link capacitor voltage control techniques and both harmonic extraction strategies during operation between PV and APF. Importance is provided to evaluating both current harmonics extraction strategies that were simulated in conjunction with the DC link capacitor voltage control approach.

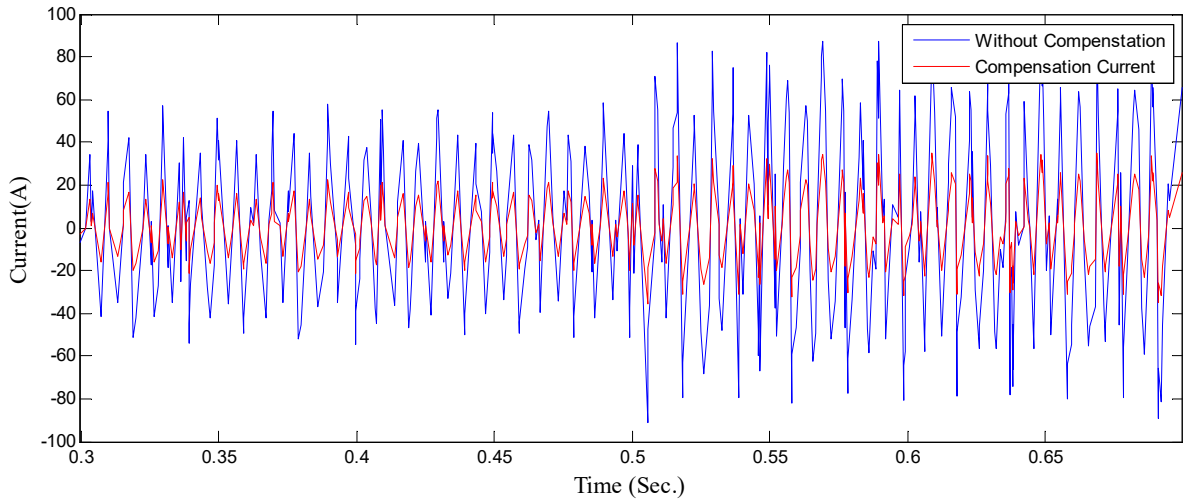


*a*

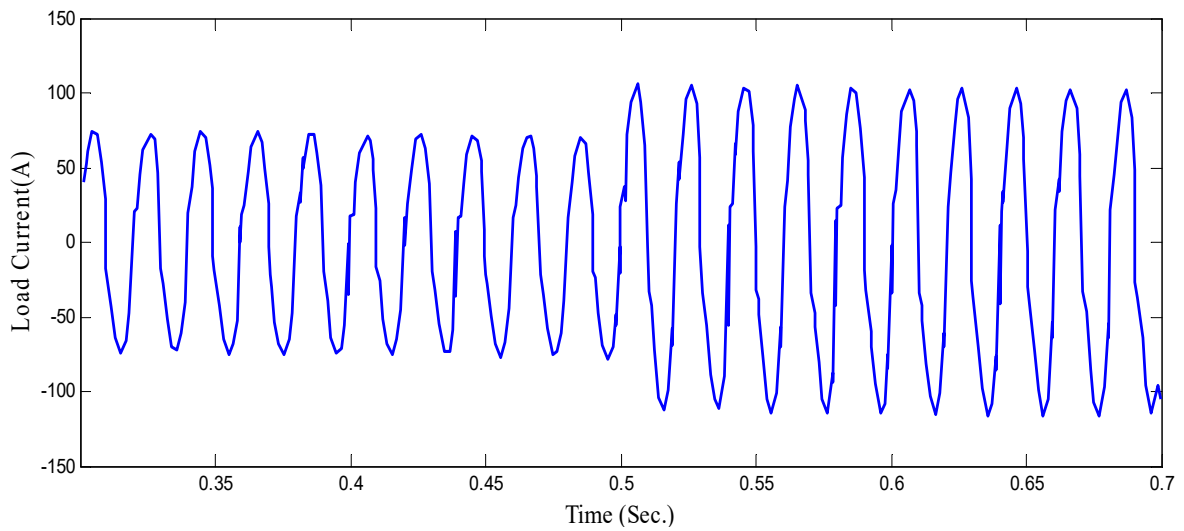


*b*

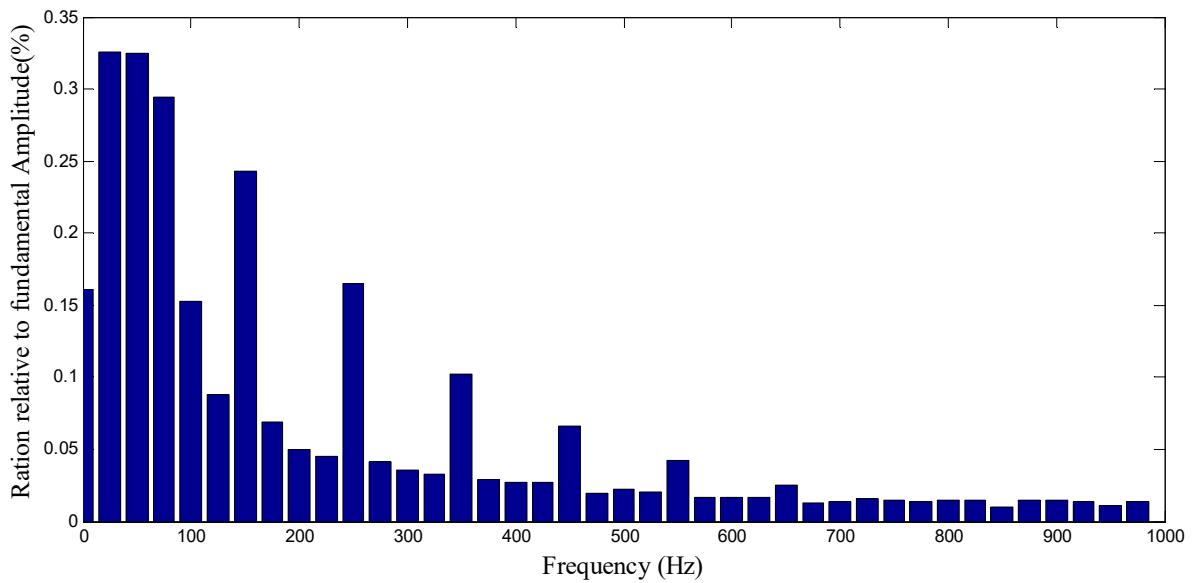
Fig. 7. Effect of load change: *a* – load current; *b* – FFT of load current



*a*



*b*



*c*

Fig. 8. Simulation results of the proposed control: *a* – load tracking current; *b* – current compensated; *c* – current FFT compensation

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## 6. Discussion of the research results of harmonic suppression compensation of photovoltaic generation using cascaded active power filter

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The analysis of the compensation of the error of photovoltaic grid-connected generation based on optimized H-bridge cascaded APF was done in Matlab/Simulink.

The results demonstrate that the method is highly promising, and the average value of the DC side voltage is essentially stable, meeting the basic requirements of voltage control. The proposed algorithms, which cover PV penetration during off-on operation and change of irradiance from low to high, were evaluated through simulations conducted under dynamic conditions. Overshoot, undershoot, response time, and energy losses were among the primary characteristics investigated.

Furthermore, the simulation results show that the compensated grid-side current is steady following an abrupt load change with a high level of precision in the steady state. Indeed, the proposed method has a lot of potential in terms of improving harmonic current tracking. Nonlinearities in the APF system, such as nonlinear loads and parameter fluctuations, can be adjusted, resulting in increased power dynamic performance. When comparing the presented work to the frequency domain, the proposed technique achieves an accuracy of solution quality. However, additional enhancements are required due to the algorithm's remaining unneeded qualities. They do not fulfill the fundamental criterion of detecting current harmonics. Because of the sluggish learning rate and the possibility of a big average error, these superfluous qualities have an impact on the algorithm's efficiency.

For the future research, neural network control and adaptive fuzzy neural network control are two approaches

that can be used to minimize harmonic current. Furthermore, it was observed from Fig. 8, *c* that the amplitude of fundamental is 0.15 % at 60 Hz while it was 9 % in the previous case.

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## 7. Conclusions

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1. A new algorithm for extracting current harmonics from APF combined with a PV source has been described. Based on the optimized H-bridge cascade APF, the presented research optimized the strong and united control strategy of the photovoltaic energy and active filter. Moreover, the proposed algorithm showed positive significance for optimizing the quality of photovoltaic grid-connected power, reducing the current harmonic, and improving the equipment utilization of photovoltaic inverters.

2. The SVSLCI algorithm is effective to suppress the deviation of the harmonic detection current and thereby decrease the harmonic content of the current on the grid. The presented control approach validates the current harmonics extraction method's significantly superior efficiency over the existing algorithms. Furthermore, it was concluded that the amplitude of fundamental decreased from 9 % to 0.15 % at 60 Hz.

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## References

- Chen, Y.-M., O'Connell, R. M. (1997). Active power line conditioner with a neural network control. *IEEE Transactions on Industry Applications*, 33 (4), 1131–1136. doi: <http://doi.org/10.1109/28.605758>
- Blaabjerg, F., Chen, Z., Kjaer, S. B. (2004). Power Electronics as Efficient Interface in Dispersed Power Generation Systems. *IEEE Transactions on Power Electronics*, 19 (5), 1184–1194. doi: <http://doi.org/10.1109/tpel.2004.833453>
- Asiminoel, L., Blaabjerg, F., Hansen, S. (2007). Detection is key – Harmonic detection methods for active power filter applications. *IEEE Industry Applications Magazine*, 13 (4), 22–33. doi: <http://doi.org/10.1109/mia.2007.4283506>
- Demirdelen, T., Inci, M., Bayindir, K. C., Tumay, M. (2013). Review of hybrid active power filter topologies and controllers. *4th International Conference on Power Engineering, Energy and Electrical Drives*, 587–592. doi: <http://doi.org/10.1109/powereng.2013.6635674>
- Wang, L., Lam, C.-S., Wong, M.-C. (2017). Modeling and Parameter Design of Thyristor-Controlled LC-Coupled Hybrid Active Power Filter (TCLC-HAPF) for Unbalanced Compensation. *IEEE Transactions on Industrial Electronics*, 64 (3), 1827–1840. doi: <http://doi.org/10.1109/tie.2016.2625239>
- Jiang, W., Ding, X., Ni, Y., Wang, J., Wang, L., Ma, W. (2018). An Improved Deadbeat Control for a Three-Phase Three-Line Active Power Filter With Current-Tracking Error Compensation. *IEEE Transactions on Power Electronics*, 33 (3), 2061–2072. doi: <http://doi.org/10.1109/tpel.2017.2693325>
- Jain, C., Singh, B. (2015). Single – phase single – stage multifunctional grid interfaced solar photo – voltaic system under abnormal grid conditions. *IET Generation, Transmission & Distribution*, 9 (10), 886–894. doi: <http://doi.org/10.1049/iet-gtd.2014.0533>
- Chilipi, R. R., Al Sayari, N., Beig, A. R., Al Hosani, K. (2016). A Multitasking Control Algorithm for Grid-Connected Inverters in Distributed Generation Applications Using Adaptive Noise Cancellation Filters. *IEEE Transactions on Energy Conversion*, 31 (2), 714–727. doi: <http://doi.org/10.1109/tec.2015.2510662>
- Zhou, Y., Li, H. (2014). Analysis and Suppression of Leakage Current in Cascaded-Multilevel-Inverter-Based PV Systems. *IEEE Transactions on Power Electronics*, 29 (10), 5265–5277. doi: <http://doi.org/10.1109/tpel.2013.2289939>
- Hoon, Y., Mohd Radzi, M., Hassan, M., Mailah, N. (2017). Control Algorithms of Shunt Active Power Filter for Harmonics Mitigation: A Review. *Energies*, 10 (12), 2038. doi: <http://doi.org/10.3390/en10122038>
- Singh, B., Verma, V., Solanki, J. (2007). Neural Network-Based Selective Compensation of Current Quality Problems in Distribution System. *IEEE Transactions on Industrial Electronics*, 54 (1), 53–60. doi: <http://doi.org/10.1109/tie.2006.888754>



12. Campanhol, L. B. G., da Silva, S. A. O., de Oliveira, A. A., Bacon, V. D. (2017). Single-Stage Three-Phase Grid-Tied PV System With Universal Filtering Capability Applied to DG Systems and AC Microgrids. *IEEE Transactions on Power Electronics*, 32 (12), 9131–9142. doi: <http://doi.org/10.1109/tpel.2017.2659381>
13. Dong, D., Luo, F., Zhang, X., Boroyevich, D., Mattavelli, P. (2013). Grid-Interface Bidirectional Converter for Residential DC Distribution Systems – Part 2: AC and DC Interface Design With Passive Components Minimization. *IEEE Transactions on Power Electronics*, 28 (4), 1667–1679. doi: <http://doi.org/10.1109/tpel.2012.2213614>
14. Shayani, R. A., de Oliveira, M. A. G. (2011). Photovoltaic Generation Penetration Limits in Radial Distribution Systems. *IEEE Transactions on Power Systems*, 26 (3), 1625–1631. doi: <http://doi.org/10.1109/tpwrs.2010.2077656>
15. Zhou, T., Francois, B. (2011). Energy Management and Power Control of a Hybrid Active Wind Generator for Distributed Power Generation and Grid Integration. *IEEE Transactions on Industrial Electronics*, 58 (1), 95–104. doi: <http://doi.org/10.1109/tie.2010.2046580>
16. Singh, M., Khadkikar, V., Chandra, A., Varma, R. K. (2011). Grid Interconnection of Renewable Energy Sources at the Distribution Level With Power-Quality Improvement Features. *IEEE Transactions on Power Delivery*, 26 (1), 307–315. doi: <http://doi.org/10.1109/tpwrd.2010.2081384>
17. Akorede, M. F., Hizam, H., Poursmaeil, E. (2010). Distributed energy resources and benefits to the environment. *Renewable and Sustainable Energy Reviews*, 14 (2), 724–734. doi: <http://doi.org/10.1016/j.rser.2009.10.025>
18. Mozina, C. (2010). Impact of Green Power Distributed Generation. *IEEE Industry Applications Magazine*, 16 (4), 55–62. doi: <http://doi.org/10.1109/mias.2010.936970>
19. Karanki, S. B., Geddada, N., Mishra, M. K., Kumar, B. K. (2013). A Modified Three-Phase Four-Wire UPQC Topology With Reduced DC-Link Voltage Rating. *IEEE Transactions on Industrial Electronics*, 60 (9), 3555–3566. doi: <http://doi.org/10.1109/tie.2012.2206333>
20. Renukadevi V., Jayanand, B. (2015). Harmonic and Reactive Power Compensation of Grid Connected Photovoltaic System. *Procedia Technology*, 21, 438–442. doi: <http://doi.org/10.1016/j.protcy.2015.10.067>
21. Somayajula, D., Crow, M. L. (2014). An Ultracapacitor Integrated Power Conditioner for Intermittency Smoothing and Improving Power Quality of Distribution Grid. *IEEE Transactions on Sustainable Energy*, 5 (4), 1145–1155. doi: <http://doi.org/10.1109/tste.2014.2334622>