

A control scheme employing an adaptive hysteresis current controller and an uncomplicated reference current generator for a single-phase shunt active power filter

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Abstract: In recent years, active power filters (APFs) have become popular because of their excellent current harmonics and reactive power mitigation ability. The performance of the APF is directly related to the selected control strategy, which is mainly divided into 2, the reference current generation and current control. Most of the reference current generation methods are very complicated and require precise mathematical expressions. Moreover, being the most preferred current control method, conventional hysteresis controllers have a fixed bandwidth, which causes different total demand distortion values under different load conditions. In this study, a novel control scheme for a single-phase shunt APF is proposed. The proposed scheme uses an uncomplicated modification of the sine multiplication method for extraction of the reference filter current. Moreover, it employs an adaptive hysteresis current controller that changes its bandwidth according to the active power demand of the load. Thus, the requirements of the current harmonics limits specified in IEEE Std. 519-1992 are always fulfilled under different load conditions. A single-phase shunt APF controlled by the proposed scheme is modeled and simulated under nonlinear load conditions using MATLAB/Simulink. The simulation results indicate that the APF effectively compensates the current harmonics and reactive power at the point of common coupling of the AC mains.

Key words: Active power filter, hysteresis current controller, sine multiplication method, fuzzy logic, reference current generator

1. Introduction

Since electrical motors were first used in industrial processes, reactive power has been a power quality problem that power engineers have had to deal with. At that time, the power quality problem sourced by an end-user was equal to the reactive power. Governments constituted standards and penalties for only the limitation of reactive power that industrial facilities drew from AC mains.

However, advances in the power engineering area increased the usage percentage of power semiconductors in both domestic and industrial devices. Unfortunately, these devices had one basic disadvantage, aside from their many advantages like speed, stability, and physical dimensions compared to old technology-based devices. Their V-I characteristics were nonlinear; thus, the current that they drew from the AC utility contained harmonic content. These harmonic currents deteriorated the point of common coupling (PCC) voltage by causing an occurrence of the voltage harmonics. As a result, the other loads supplied from same point were badly affected, even though they had linear V-I characteristics [1]. The power quality problem sourced by the end-user did not mean only reactive power anymore, it also included current harmonics.

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In some papers in the literature, the terms active power line conditioner, active power quality conditioner, or instantaneous reactive power compensator are often used instead of active power filter (APF) [2], which presents a powerful and tunable solution for compensating current harmonics and reactive power simultaneously. The main objective of the APF is injecting the harmonic and reactive component of the load current with the opposite sign. Hence, all of the harmonic and reactive components need of load is provided by the filter and source current will be completely formed by the fundamental component and in phase with the source voltage.

Control schemes of the APFs generally consist of 2 parts, the reference filter current generator and current controller circuit. For single-phase reference filter current generation, various techniques like pq-theory [3], dq-transformation [4], multiplication with a sine function [5], and Fourier transform [6] have been investigated in different studies. For the current control part, a hysteresis current controller (HCC) is mostly preferred in APF control schemes because of its excellent advantages, like easy and inexpensive implementation, quick current controllability, and perfect stability. However, with this technique, controlling the APF converter switching frequency is not feasible. In spite of this drawback, the irresistible harmonic compensation performance of the HCC compared to its competitor, the sawtooth-error signal comparing method, makes it an indispensable part of the APF. Moreover, some modifications to this method have been investigated in the literature [7,8].

In this study, a novel control scheme for a single-phase shunt APF is proposed. A fuzzy logic-based DC bus voltage regulator-assisted sine multiplication method constitutes the reference filter current generator part of the proposed control scheme. As for the current controller, an adaptive HCC is employed, which aims to hold the total demand distortion (TDD) constant under varying load conditions rather than the switching frequency. At the output stage of the control scheme, pulse-width modulation (PWM) signals, which will be applied to the power semiconductors of the APF converter, are produced.

In many papers about APFs, results are given only for 1 fixed load condition or a maximum for 1 load change. However, in this paper, 3 load conditions with 2 changes are considered, to point out the performance of the proposed control scheme at the transient and steady-state cases. The first change is a 2-fold increment from the starting values and the second change is a 4-fold decrement from the second values.

2. The importance of current harmonics mitigation

In IEEE Std. 519-1992 (IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems) [9], some definitions about the design of electrical systems that include both linear and nonlinear loads are given, harmonic generation sources and effects of harmonics are described, and key parameters for the measurement, analysis, limitation, and compensation of both reactive power and harmonics are explained. Most governments recognize this standard as their national power quality standard.

In this standard, the effects of current harmonics on other loads are explained with a situation like that in Figure 1, which shows a nonlinear load supplied from a power source (G) over a 3-phase line (L_1).

The reactance of the source (X_G), the first transformer (X_{T1}), and the line L_1 (X_{L1}) are in series with the nonlinear load transformer reactance (X_{T2}). If the nonlinear load draws harmonic current from the source, there will be a harmonic voltage drop and it will affect the waveform of the voltage at the PCC B , as shown in Eqs. (1) and (2):

$$X_H = X_G + X_{T1} + X_{L1} + X_{T2}, \quad (1)$$

$$V_{BH} = V_G - I_H \times X_H, \quad (2)$$

where X_H is the reactance of the current path from the source to the nonlinear load at the specified current

harmonic frequency and V_{BH} is the voltage of the PCC B , which has a voltage harmonics content. If there are other loads supplied from the same point over the line L_2 , the harmonic voltage at the point of B will lead to the harmonic currents drawn by these loads even if they have linear characteristics.

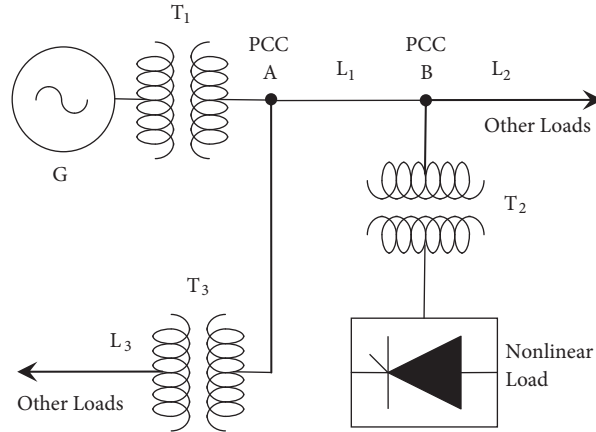


Figure 1. Harmonic influences in a power system.

To prevent the effects of the current harmonics on other loads, IEEE Std. 519-1992 also introduces current harmonics limits for distribution system consumers, as shown in Table 1. In Table 1, the TDD is defined as the total root-sum-square harmonic current distortion, in percent of the maximum demand load current (15 or 30 min demand). It is calculated as below:

$$TDD = \frac{\sqrt{\sum_{h=2}^{40} (I_h)^2}}{I_L} \times 100. \quad (3)$$

The term TDD is very important for harmonic mitigation techniques, including APFs. In any case, consumers should not exceed the TDD limit values specified in Table 1; thus, the installed compensation circuit should aim to hold the TDD constant at these values under every load condition. In other words, it is a key parameter that shows at what degree the harmonic mitigation technique is successful.

Table 1. IEEE Std. 519-1992 current distortion limits for distribution systems (120 V through 69,000 V).

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)						
I_{SC}/I_L	< 11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	TDD
$< 20^*$	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Even harmonics are limited to 25% of the odd harmonic limits above

*All power generation equipment is limited to these values, regardless of actual I_{SC}/I_L

I_{SC} = maximum short-circuit current at PCC

I_L = maximum demand load current (fundamental frequency component) at PCC

3. Proposed APF control strategy

A generalized block diagram and the power circuit of the proposed shunt APF are shown in Figures 2 and 3, respectively. The power circuit consists of a single-phase full-bridge converter with a capacitor that acts as an energy storage component and a filter inductor, through which connection with the nonlinear load is realized. PWM signals obtained by the control circuit are applied to the converter's power switches, and thus the filter current will follow the desired reference current.

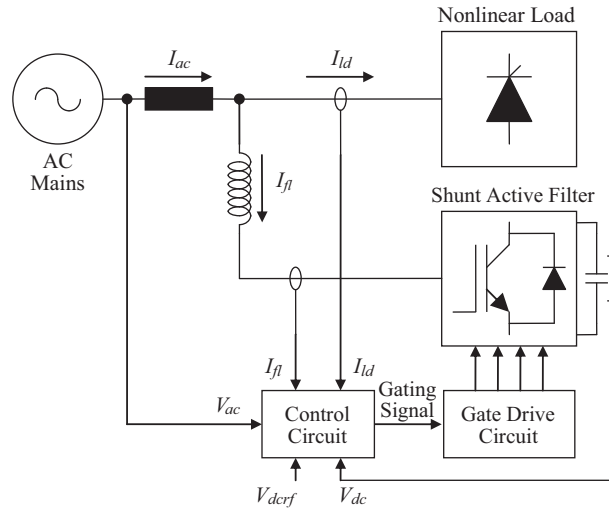


Figure 2. Generalized block diagram of the shunt APF.

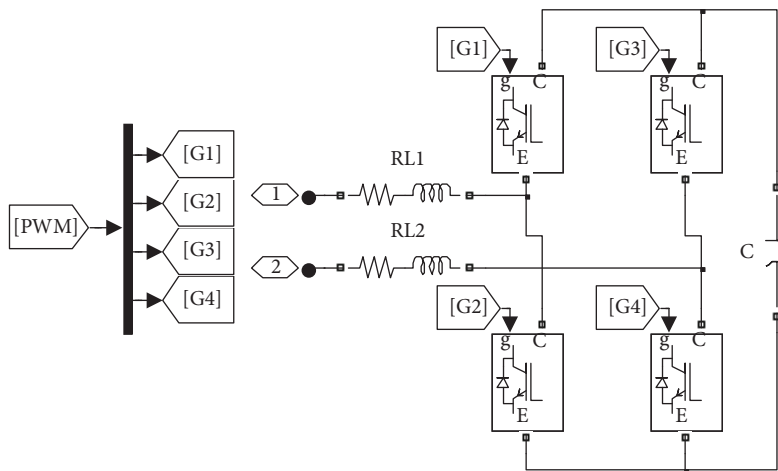


Figure 3. Simulink model of the power circuit for the shunt APF.

The Simulink model of the control scheme given in Figure 4 can be explained in 2 parts: a sine multiplication method-based reference filter current generator, which is assisted by a fuzzy logic DC voltage regulator, and an adaptive HCC.

3.1. Reference filter current generator

For the purpose of determining the reference filter current, which only contains the reactive and harmonic components of load current with opposite signs, first the reference source current should be generated, and

then the actual load current should be subtracted from this reference. This process should be done accurately to reach the desired filter performance. Toward this objective, different methods have been introduced in the literature. However, some of these methods require precise linear mathematical models, which are difficult to obtain and some of them require a large computation time.

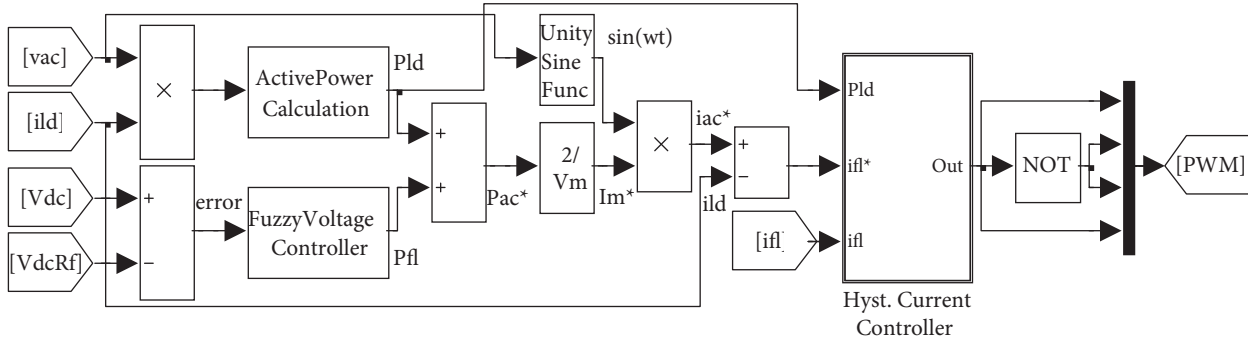


Figure 4. Simulink model of the proposed control scheme.

The APF’s capacitor voltage is also another important parameter to be elaborated on. It should be kept constant at an acceptable value. If this is not achieved, i.e. if the capacitor voltage decreases too much, the sinusoidal waveform of the source current cannot be ensured or if too much of an increment is allowed at the capacitor voltage, this will mean excessive active current drawn from source.

In this paper, for the extraction of the reference filter current, a modification of the sine multiplication method is used. The modification is provided by adding a voltage controller, which is based on the Takagi–Sugeno-type fuzzy logic system, for regulation of the APF DC bus capacitor voltage. This method is not complicated and a response time that is not more than a half cycle is achieved for loads only containing odd harmonics [10].

In this method, an assumption is made. According to this, the source current in Eq. (5) will be in the pure sinusoidal waveform and the phase angle will be the same as the source voltage in Eq. (4), after compensation. Hence, the instantaneous power drawn from the source will be calculated as in Eq. (6):

$$v_{ac}(t) = V_m \sin wt, \tag{4}$$

$$i_{ac}(t) = I_m \sin wt, \tag{5}$$

$$p_{ac}(t) = v_{ac}(t)i_{ac}(t) = V_m I_m \sin^2 wt. \tag{6}$$

If Eq. (6) is averaged for 1 cycle, the active power drawn from the source can be found as in Eq. (7):

$$P_{ac} = \frac{1}{2\pi} \int_t^{t+T} V_m I_m \sin^2 wt. dwt = \frac{V_m I_m}{2}. \tag{7}$$

Therefore, by keeping in mind that the active power drawn from the source before and after compensation will not change, if the actual active power (P_{ac}^*) is calculated, the peak value of the reference source current (I_m^*) can be easily determined, as in Eq. (8):

$$I_m^* = P_{ac}^* \frac{2}{V_m}. \tag{8}$$

Multiplying this value with a unity sine function gives the reference source current (i_{ac}^*):

$$i_{ac}^*(t) = I_m^* \sin wt = \frac{2P_{ac}^*}{V_m} \sin wt. \tag{9}$$

Finally, if the load current is subtracted from this variable, the reference filter current (i_{fl}^*) can be found:

$$i_{fl}^*(t) = i_{ac}^*(t) - i_{ld}(t). \tag{10}$$

In Eq. (8), the actual active power (P_{ac}^*) has 2 terms, as can be seen in Eq. (11):

$$P_{ac}^* = P_{ld} + P_{fl}. \tag{11}$$

The first one is the active power of the load (P_{ld}), which is calculated by multiplying the source voltage and load current, and averaging this result over one cycle, as in Eq. (12):

$$P_{ld} = \frac{1}{2\pi} \int_t^{t+T} v_{ac}(t)i_{ld}(t)dw. \tag{12}$$

The second term in Eq. (11) is the filter power coefficient rather than a real active power, which will supply the losses in the converter to regulate the DC capacitor voltage after the load changes. The filter power coefficient (P_{fl}) is determined by the Takagi–Sugeno-type fuzzy logic-based voltage controller. First the reference DC voltage (V_{dcrf}) is subtracted from the actual DC capacitor voltage and it will be the error input of the fuzzy voltage controller block in Figure 4. The inside of this block can be seen in Figure 5, where the fuzzy logic controller has 2 input variables: the error of capacitor DC voltage (e) and the change in this error (Δe). The equations of these variables at the k th sampling time are given in Eqs. (13) and (14), where α and β denote the scaling factors of the input variables.

$$e(k) = \alpha (V_{dc}(k) - V_{dcrf}) \tag{13}$$

$$\Delta e(k) = \beta (e(k) - e(k - 1)) \tag{14}$$

The output variable of the controller is the change in the filter power coefficient (ΔP_{fl}). The actual filter power coefficient is determined as in Eq. (15). Here γ is the output scaling factor.

$$P_{fl}(k) = P_{fl}(k - 1) + \gamma \Delta P_{fl}(k) \tag{15}$$

The input membership functions and rules of the fuzzy logic controller are shown in Figure 6. The rules of the fuzzy logic controller are in the form of the following expression, where X_i and Y_i denote the membership functions of the input and Z_i denotes the weighted linear output function of 1 rule and is calculated as in Eq. (16), where the rule output coefficients are denoted by a_i , b_i , and c_i , respectively, and w_i is the firing strength of the rule and calculated as in Eq. (17). The *AndMethod* is performed by taking the minimum of 2 inputs (e and Δe).

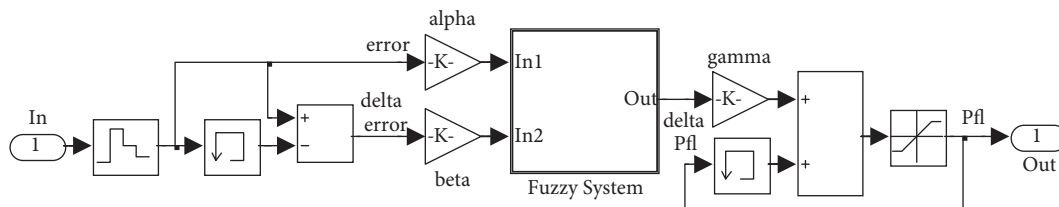


Figure 5. The inside of the fuzzy voltage controller in Figure 4.

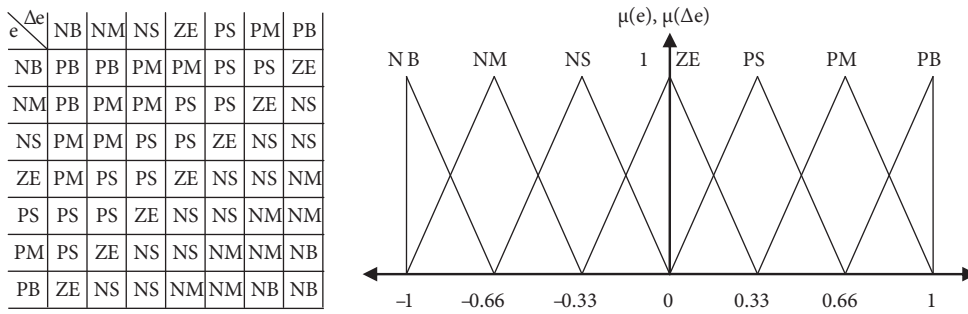


Figure 6. Membership functions and rules of the fuzzy controller for (e) and (Δe) .

IF $e(k)$ is X_i AND $\Delta e(k)$ is Y_i THEN $\Delta P_{fl}(k)$ is Z_i

$$Z_i = w_i (a_i e(k) + b_i \Delta e(k) + c_i) \tag{16}$$

$$w_i = AndMethod(X_i(e(k)), Y_i(\Delta e(k))) \tag{17}$$

If there is more than one rule matching (e) and (Δe) , the final output is calculated by dividing the sum of all of the rule output functions by the sum of all of the rule firing strengths:

$$FinalOutput = \frac{\sum_{j=1}^N Z_j}{\sum_{j=1}^N w_j} \tag{18}$$

3.2. Adaptive HCC

In the next step of the control scheme, the APF current is forced to smoothly track the previously generated reference current by applying suitable PWM signals to the power switches. For this step, the HCC method is the most preferred method because of its easy and inexpensive implementation, quick current controllability, and perfect stability. As shown in Figure 7, the main part of the HCC is the hysteresis comparator. It compares the actual filter current with the reference current. If the measured filter current reaches and wants to exceed a value that is equal to the reference current plus half of the hysteresis band value, the corresponding power switches are commutated to decrease the filter current. In contrast, if the measured current decreases until reaching a value equal to the reference current minus half of the hysteresis band value, the power switches are commutated to increase the output current. This mode of operation can be seen in Figure 8, as a filter current oscillation in a band near the reference current.

Unfortunately, in the HCC method, the switching frequency is not fixed. Because of the sinusoidal waveform, the source voltage changes suddenly with a high degree of the slope at the beginning and end of the half period, but at the middle of the half period the degree of the slope decreases and the source voltage changes slowly. Thus, to follow the reference filter current successfully, the hysteresis comparator forces the power switches to commute more frequently at the beginning and end of the half period, but at the middle of the half period the power switches are commutated less frequently. As a result, the switching frequency will change continually between the 2 peak values, where it reaches its maximum and minimum values. This situation is summarized in Figures 9 and 10. However, in spite of this disadvantage, the irresistible harmonic compensation performance of the HCC compared to its competitor sawtooth-error signal comparing method makes it an indispensable part of the APF.

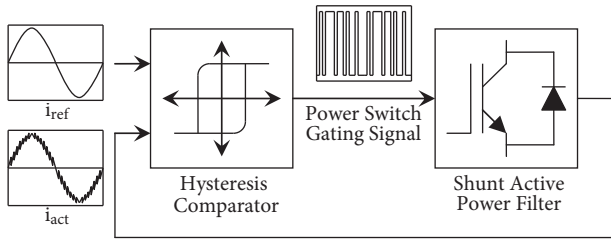


Figure 7. Block diagram of the HCC.

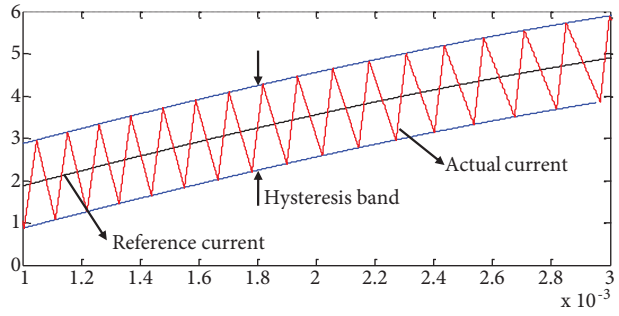


Figure 8. Reference and actual filter currents for the HCC.

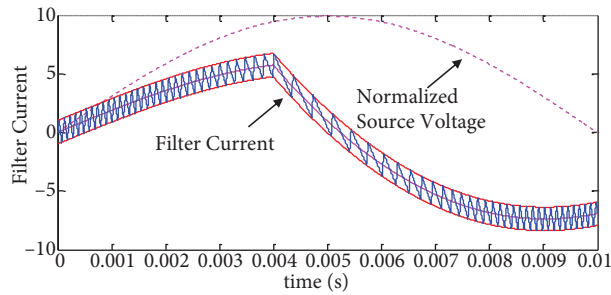


Figure 9. Variation of the APF current and normalized source voltage.

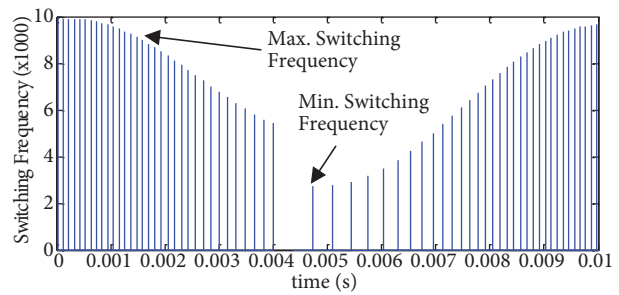


Figure 10. Instantaneous switching frequency of the APF power switches to follow the reference.

Because of the varying switching frequency, a new parameter should be defined for evaluating different HCC topologies. It will probably be the maximum switching frequency because the major parts of the APF are the power switches, and they have limited maximum switching frequency capabilities. In this paper, to calculate the instantaneous switching frequency of APF power switches, as shown in Figure 11, a new Simulink model is generated and used for comparing conventional and adaptive HCCs.

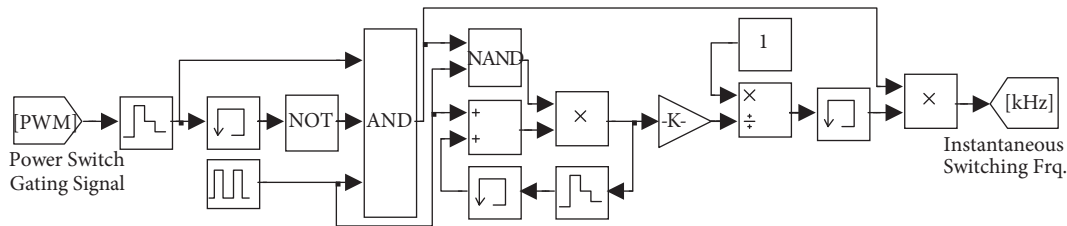


Figure 11. Simulink model of the proposed instantaneous switching frequency calculator.

In most HCCs, the hysteresis bandwidth is fixed, which is not a disadvantage if the load is also fixed. The bandwidth is adjusted to ensure the target TDD value for the initial load condition and if load is not changed, the TDD will always remain constant. However, for realistic results, the APF should be run under different load conditions, including both decrements and increments, and under each condition, the TDD value should not exceed the allowed limits. The conventional fixed hysteresis bandwidth method fails under these varying load conditions. When the active power of the load increases or decreases, regardless of the preferred reference current generation method, the amplitude of the source current will also increase or decrease. If the hysteresis bandwidth is fixed, this means that oscillations with relatively small amplitude compared to the

source current with large amplitude or oscillations with relatively large amplitude compared to source current with small amplitude. These oscillations contain higher order harmonics and according to the ratio in TDD equation, if these harmonics have small amplitudes, the TDD will decrease or, if these harmonics have large amplitudes, the TDD will increase. In both situations, the maximum switching frequency will be constant. As a result, different TDD values will be obtained under different load conditions; while some of them will be below the allowed limit unnecessarily, the others will be above the allowed limit.

In this method, the active power drawn by the load is used, which is calculated before (multiplication of the source voltage and load current, and averaging this product over one cycle) extracting the reference source current. By multiplication of the active power of the load and a specified scaling factor, the width of the hysteresis band can be determined.

In this paper, an adaptive HCC (shown in Figure 12) method is used. This method was proposed in [11] and it depends on changing the hysteresis band width according to load active power. In contrast, with this method, when the active power of the load increases or decreases, the amplitude of the source current and width of the hysteresis band will increase or decrease together, and the ratio of the (amplitude of the oscillations, and thereby the amplitude of higher order harmonics) / (amplitude of source current) will not be changed. As a result, according to the ratio in the TDD equation, the total harmonic distortion will remain constant, fulfilling the requirements of the current harmonics limits specified in IEEE Std 519-1992 given in Table 1, while the switching frequency will decrease or increase.

4. Simulation results

The performance of the proposed control scheme designed for a single-phase shunt APF is tested under a nonlinear AC regulator load, as shown in Figure 13. Simulations are carried out using MATLAB/Simulink and the results are presented in Figures 14–25. Figures 14–21 are given for the proposed reference current generator and adaptive HCC and Figures 22–25 are given to compare the proposed adaptive and standard HCCs. The simulation parameters are listed in Table 2.

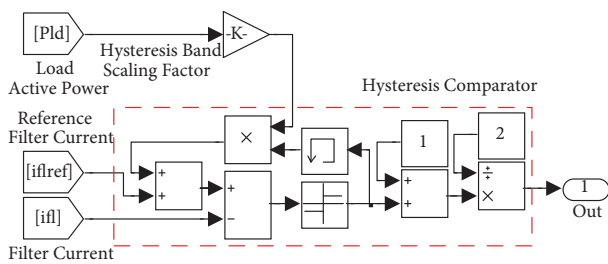


Figure 12. Simulink model of the proposed adaptive HCC.

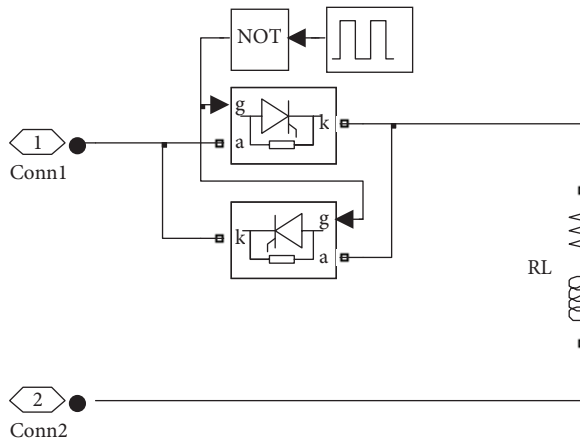


Figure 13. Nonlinear AC regulator load.

Figure 14 shows the active and reactive powers drawn by the load, which increase from 912 W (1136 VAR) to 1824 W (2272 VAR) and decrease from these values to 456 W (568 VAR). Figure 15 shows the variation of the load current and source voltage, and Figure 16 shows the TDD of the load current during and after these load changes.

Table 2. Circuit parameters of the APF.

Parameter	Value
Source voltage (peak value)	311 V
Source frequency	50 Hz
Inductance of coupling bobbin	0.002 H
Resistance of coupling bobbin	1 Ω
DC bus capacitor	470 μ F
DC bus reference voltage	400 V
Resistance of first load	20 Ω
Inductance of first load	0.05 H
Resistance of second load	10 Ω
Inductance of second load	0.025 H
Resistance of third load	40 Ω
Inductance of third load	0.1 H

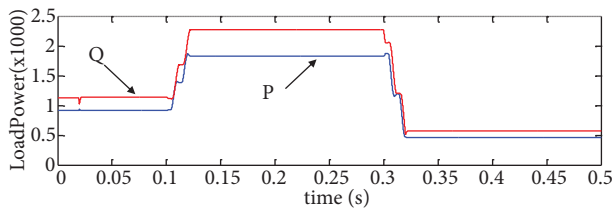


Figure 14. Variation in the active and reactive powers of the load.

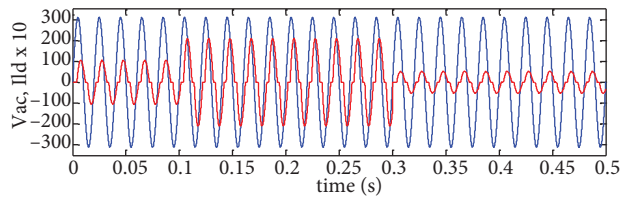


Figure 15. Variation in the load current and source voltage.

Figure 17 shows the variation in the filter current and source voltage. As seen from Figure 17, the APF provides the reactive and harmonic content of the load current. Figure 18 shows the active and reactive powers drawn by the filter, where it is seen that the APF provides not only the reactive power demand of load but also balances the active power demand of the load during sudden load changes. With the exception of these load changes, the APF draws only a small amount of active power from the source for supplying losses in its circuit.

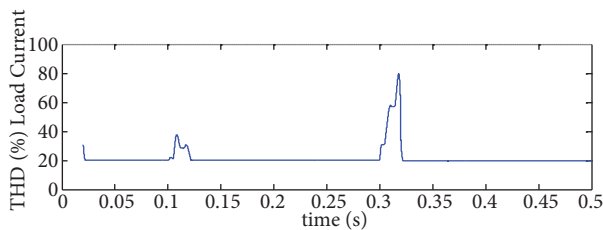


Figure 16. Variation in the TDD (%) for the load current.

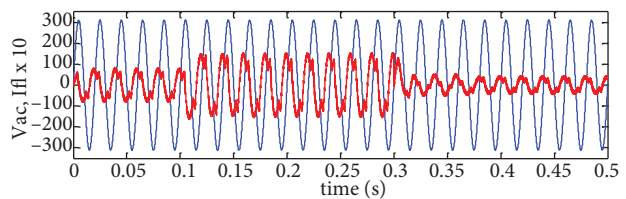


Figure 17. Variation in the filter current and source voltage.

As a result, the total current and active and reactive powers drawn from the source are shown in Figures 19 and 20, where it is seen that all of the harmonic and reactive component needs of the load are provided by the filter, so the source current is completely formed by the fundamental component and in phase with the source voltage. The reactive power is drawn from the source only during load changes, which can be seen in Figure 20 as small oscillations.

Figure 21 shows the variation in the DC bus voltage and its mean value, which is an important parameter

of the APF. As seen from Figure 21, thanks to the excellent performance of the fuzzy logic controller, even under these heavy load changes, the DC bus voltage settles the predefined reference value in a very short time.

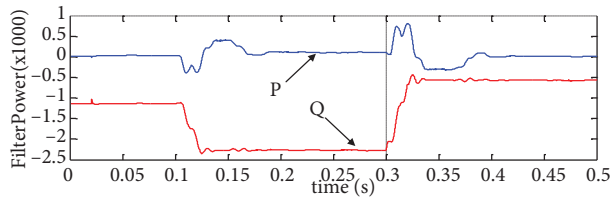


Figure 18. Variation in the active and reactive powers of the filter.

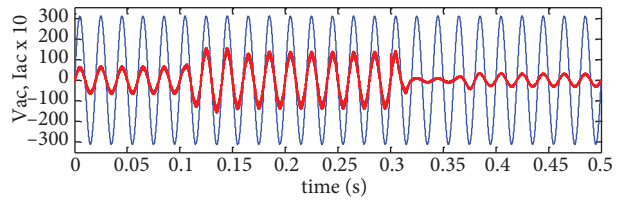


Figure 19. Variation in the source current and source voltage.

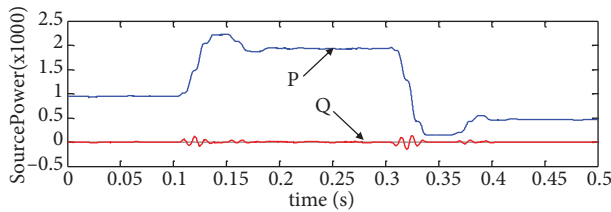


Figure 20. Variation in the total active and reactive powers drawn from the source.

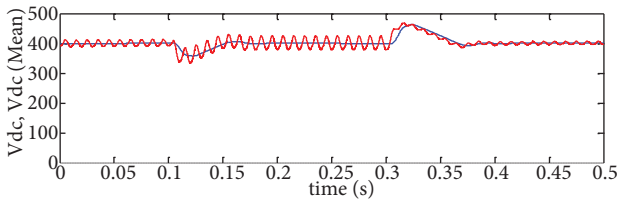


Figure 21. Variation in the DC capacitor voltage under load changes.

Figure 22 shows the variation in the TDD (%) with the proposed adaptive HCC under load changes. As seen from Figure 22, until the first load change, the TDD is 5%, which fulfills the requirements of the current harmonics limits specified in IEEE Std 519-1992. After the load change (2 times the increment), the TDD makes oscillations, which takes about 0.075 s, and settles at the allowed value again. At 0.3 s, a 4-fold decrement occurs in the load demand and the TDD makes oscillations again, but even under this heavy load change it settles at the allowed value again in about 0.1 s.

On the other hand, Figure 23 shows the variation in the TDD (%) with a standard HCC under the same load changes. With this method, until the first load change the TDD is 5%, but after the load change oscillations it decreases unnecessarily to 2.5%, which is half of the allowed limit. One can say that a decrease under the current harmonic limitation is a better case because a lower TDD means a lower harmonic distortion and smoother sinusoidal waveform. However, the disadvantage of this method appears after the second load change. This time the TDD increases to 10%, which is 2 times higher than the allowed limit, because the hysteresis band is fixed and adjusted for the first load condition.

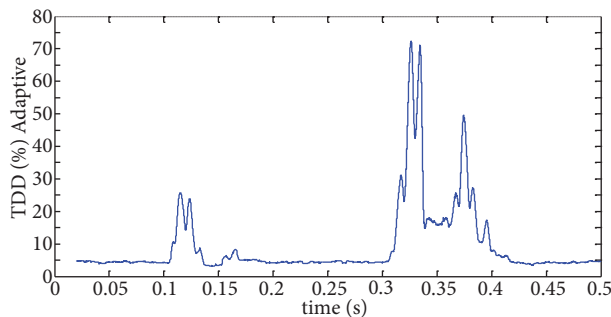


Figure 22. Variation in the TDD (%) for the source current with the proposed adaptive HCC.

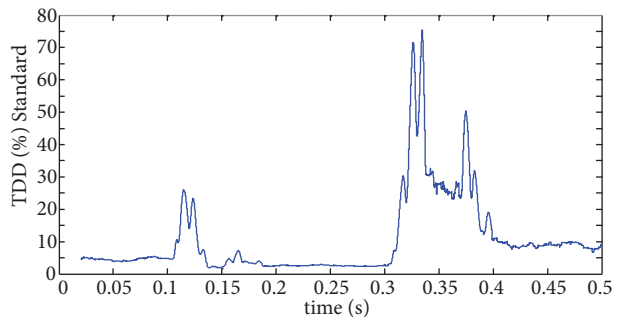


Figure 23. Variation in the TDD (%) for the source current with the standard HCC.

To present another advantage of the proposed method, Figures 24 and 25 are given, showing the instantaneous switching frequency of the power switches, which are obtained by the model presented in Figure 11. In Figure 24, the standard HCC maximum switching frequency remains nearly constant, except at the load changing times. At first look, it seems to be an advantage, but, as mentioned previously, after the first load change, the TDD decreases from 5% to 2.5% and, after the second load change, it increases to 10%. This is about the ratio of the (hysteresis bandwidth) / (amplitude of reference source current). This ratio decreases at the second load condition (because the hysteresis bandwidth is fixed and the amplitude of the reference source current increases), which means the reference will be followed more strictly with a lower TDD. This ratio increases at the third load condition (because the hysteresis bandwidth is fixed and the amplitude of the reference source current decreases), which means that the filter current will oscillate in a relatively large band, causing a higher TDD. As a result, to fulfill the requirements of the current harmonics limits specified in IEEE Std. 519-1992 with a standard HCC, the hysteresis bandwidth should be adjusted for the worst case. This means the filter's power switches will always be commuted at a higher frequency, which is not a necessity for the other cases.

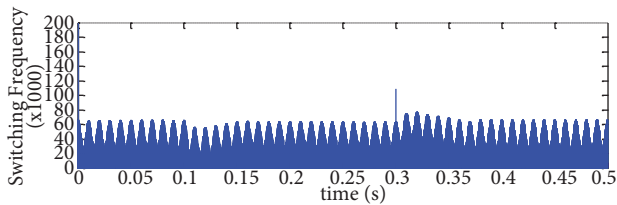


Figure 24. Instantaneous switching frequency of the power switches with the standard HCC.

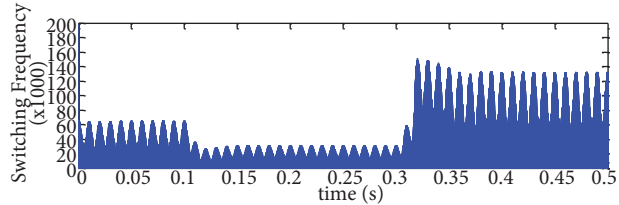


Figure 25. Instantaneous switching frequency of the power switches with the adaptive HCC.

In contrast, in Figure 25 with the adaptive HCC, to keep the TDD constant at 5%, the maximum switching frequency changes according to the active power of the load. The proposed method gives priority to the TDD. If the requirements of the current harmonics limits are fulfilled, then the switching frequency can be decreased or if the TDD is above the limits, the switching frequency can be increased. Hence, the filter's power switches do not always need to be commuted at a higher frequency and the switching power losses will decrease.

5. Conclusion

In this study, to compensate the current harmonics and reactive power of nonlinear loads, a novel control scheme for a single-phase shunt APF is proposed. In the proposed control scheme, for the extraction of the reference filter current, a modification of the sine function multiplication method is used. The modification is provided by adding a voltage controller, which is based on the Takagi–Sugeno-type fuzzy logic system, for regulation of the APF DC bus capacitor voltage and an adaptive HCC is used to obtain PWM signals for the converter's power switches. For general and realistic results, unlike those in many papers about this subject, the APF with the proposed controller is tested under different load conditions, including both load decrements and increments. From the simulation results, it is seen that the APF provides the reactive power demand of the load, and thus nearly zero reactive power is drawn from the source. With the proposed adaptive HCC, after each load change, the TDD value of the input source current settles again at the allowed limits specified in IEEE Std. 519-1992. In contrast, with the traditional HCC, different TDD values are obtained under the same load conditions, while some of them are unnecessarily below the allowed limits and some of them are above. Moreover, after each load change, the DC bus voltage, which is an important parameter of the APF, settles at a predefined reference

value in a very short time by means of the excellent performance of the fuzzy logic voltage controller. Hence, any possible negative effect caused by the DC bus voltage oscillation on the source current is prevented.

6. Future works

This study is the part of a doctoral thesis entitled ‘Design and implementation of an artificial intelligence-based controller for active power filters’ and contains theoretical analyses and simulation results. Practical application is still in progress. As soon as it is finished, more comprehensive theoretical and practical analyses supported by the experimental results will be available.

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