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TİP-2 SİNİRSEL-BULANIK DENETLEYİCİ İLE ŞÖNT AKTİF GÜÇ FİLTRESİNİN DENETİMİ

CONTROL OF SHUNT ACTIVE POWER FILTER WITH TYPE-2 NEURO-FUZZY CONTROLLER

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ÖZET

Günümüzde doğrusal olmayan yüklerin yaygın kullanımı, enerji kalitesindeki sorunların artmasına neden olmaktadır. Bu problemler harmonik kirlilik ve reaktif güç olarak düşünülebilir. Geleneksel olarak, pasif filtrelerle harmonik dengeleme yapılmaktadır, ancak bu filtreler tek boyutlu bir çözüm sunmaktadır. Pasif filtrelerin sabit kompanzasyon özellikleri ve büyük güçlerde büyük boyutlar gibi dezavantajları bulunmaktadır. Bu nedenlerden dolayı, pasif filtreler harmonikleri baskılamak için yetersizdir. Mikroişlemci ve güç elektroniği teknolojileri, aynı anda harmonik ve reaktif güç kompanzasyonu gerçekleştirebilen aktif güç filtrelerinin kullanılmasına izin vermektedir. Bu çalışmada, harmonik ve reaktif güç kompanzasyonunu gerçekleştirebilen şönt aktif güç filtresinin (ŞAGF) benzetim modeli, Matlab/Simulink paket programı kullanılarak geliştirilmiştir. ŞAGF'nin DA-hat gerilimini denetlemek için, tip-2 sinirsel-bulanık denetleyici (T2SBD) önerilmiştir. Önerilen denetleyici ile PI denetleyici aynı koşullar altında karşılaştırılmıştır. Elde edilen sonuçlara göre, T2SBD'nin PI denetleyiciye göre daha iyi performansa sahip olduğu gözlemlenmiştir.

Anahtar Kelimeler: ŞAGF, Tip-2 Sinirsel-Bulanık Denetleyici, Enerji Kalitesi, Harmonikler

ABSTRACT

Today, the widespread use of nonlinear loads has led to an increase in electric power quality problems. These problems are harmonic pollution and reactive power. Traditionally, harmonic compensation is carried out by passive filters, but such filters offer a one-dimensional solution. Passive filters have disadvantages such as fixed compensation characteristics and large sizes at large powers. For all these reasons, passive filters are insufficient to suppress harmonics. The emerging microprocessor and power electronics technologies allow the use of active power filters that can perform harmonic and reactive power compensation at the same time. In this study, simulation model of a shunt active power filter (SAPF), which can perform harmonic and reactive power compensation at the same time, is created using Matlab/Simulink package program. To control DC-link voltage of SAPF, type-2 fuzzy neural network controller (T2FNNC) is proposed. SAPF with the proposed controller is compared with the PI controller under the same conditions. The performance of SAPF structure with the proposed controller has been examined with the simulations studies.

Keywords: SAPF, Type-2 Fuzzy Neural Network Controller, Power Quality, Harmonics

1. INTRODUCTION

In recent years, as a result of the rapid development of switching and capacitors in power electronic devices, the use of these devices in electrical devices and industrial field has become widespread. According to the operating principles of power electronic elements, currents drawn from the grid are not pure sinusoidal. The circuit elements that have no linear relationship between applied voltage and current are defined as nonlinear elements, and loads containing such elements are nonlinear loads. These loads draw non-sinusoidal currents from grid. Non-sinusoidal currents cause undesirable effects in electrical systems. Today, passive filters or active filters can be used to eliminate or reduce these effects. Passive filters are not very efficient in terms of performance and size. The active power filter (APF) can perform many features such as harmonic suppression, reactive power compensation and voltage regulation [1-5]. These filters can also provide adaptation to load change. These advantages of APFs have made them a more popular subject and have led to many studies for these filters. It is necessary to introduce some standards for harmonic distortions. According to IEEE 519 standard, current harmonic distortion is 5% and voltage harmonic distortion is 3%. The basic operating principle of APF is to generate currents or voltages of the same amplitude and opposite phase to harmonics produced by nonlinear loads using power electronic elements and to give these currents or voltages to the system. Therefore, the harmonics generated by the power electronics devices are destroyed by using the elements of power electronics [5-9].
In control of DC-link voltage of SAPF, traditional controllers such as PI and PID controller are preferred. But these controllers have some negative features. It is well-known that many intelligent controllers and control algorithms are widely used instead of these controllers [7-9]. Type-1 fuzzy logic concept was originally presented by Zadeh in 1965 and operates on fuzzy sets [10]. In a system using a traditional set, the value of the input variable is 0 or 1. The membership degree in the set where the input variable is located has a value between 0 and 1. The boundaries of type-1 fuzzy set are sharp values determined by the expert. Similarly, the membership degree of a variable belonging to one of these sets is also a sharp value. Therefore, conventional fuzzy sets cannot fully express high uncertainties. In addition, the determination of membership functions, set boundaries and rule bases lead to new uncertainties in the system. As a consequence, a new type of fuzzy sets which also models uncertainties, was introduced by Zadeh in 1975 [11]. While the membership degree of an input variable of type-1 fuzzy set is a sharp value, the membership degree of variable of type-2 fuzzy set is also fuzzy. Type-1 fuzzy sets have some limitations, such as expressing cluster uncertainties and non-linearities while type-2 fuzzy sets are used to reduce the effects of these constraints [12-18]. In this study, SAPF is modelled in Matlab/Simulink program and control of the modelled system is performed with type-2 fuzzy neural network controller (T2FNNC). In addition, the performance of the proposed controller in SAPF structure has been investigated.

2. MATHEMATICAL MODEL OF SHUNT ACTIVE POWER FILTER

Akagi first described the instantaneous reactive power theory in 1983 [4]. This method is also known as the p-q theory. The p-q theory consists of an algebraic transformation in αβ0 coordinates of three-phase currents and voltages in the a-b-c coordinates. From these αβ components, active and reactive instantaneous power components can be calculated [4-5]. The instantaneous power method does not require the separately determination of each harmonic in the load current. This theory which uses the load current and the source voltage for the calculation is instantaneous and consists of calculation circuits that produce a compensation current that will complement the full sine-wave to the measured current. The main advantages of this theory are that it requires a small number of components and compensates for harmonic components [4-5].

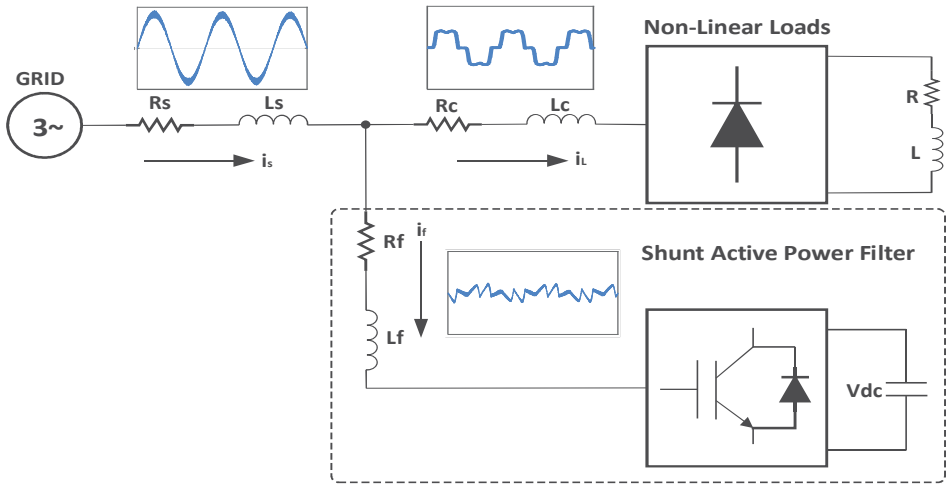


Figure 1. Configuration of SAPF

In a three-phase balanced system, the grid voltage and α-β transformations are given in the following equations:

$$\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix}$$

(1)

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1/\sqrt{2} & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

(2)

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad (3)$$

Where, V_{sa}, V_{sb} and V_{sc} are grid voltages. i_a, i_b and i_c are grid currents. According to instantaneous power theory, the following equations can be obtained in matrix form as:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (4)$$

Current components in the αβ-axes can be written as:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p \\ q \end{bmatrix} \quad (5)$$

The instantaneous real power (P) and imaginary power (Q) related with αβ-axis currents and voltages can be written as:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{6}$$

In this theory, P and Q can be selected independently and expressed as:

$$p = \overline{p} + \tilde{p} \tag{7}$$

$$q = \overline{q} + \tilde{q} \tag{8}$$

Where, the mean value of the instantaneous real power and the instantaneous imaginary power are symbolized as $\overline{p}$ and $\overline{q}$, respectively. The instantaneous compensating currents are expressed as follows:

$$\begin{bmatrix} i_{f\alpha} \\ i_{f\beta} \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} -\tilde{p} \\ -q \end{bmatrix} \tag{9}$$

The reference compensating current in the abc-axes can be obtained by means of the equations given above:

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{f\alpha}^* \\ i_{f\beta}^* \end{bmatrix} \tag{10}$$

3. TYPE-2 FUZZY NEURAL NETWORK CONTROLLER

Fuzzy logic systems (FLSs) and Artificial neural networks (ANNs) have been widely used artificial intelligent methods. ANNs have advantages such as learning capability from input-output data, generalization capability, and FLSs have the advantages such as using expert knowledge and inferences capability. Neuro-fuzzy controllers (NFCs) are realized by using both methods in same architecture, NFCs have the advantages of ANNs and FLSs. FLSs are designed by using two common techniques as type-1 FLS and type-2 FLS. Type-1 FLSs may not ensure the desired performance in systems with large amount of uncertainties [12-15]. In these cases, type-2 FLSs can replace for the type-1 FLSs. Type-2 FLSs have been proposed in many areas, such as DC-DC converter control, controlling of mobile robots, and motor control [11-18]. Type-2 neuro-fuzzy controller (T2NFC) used in this paper has a structure with multiple-input and single-output using type-2 Takagi-Sugeno-Kang (TSK) fuzzy rules. T2NFC fuzzy rules used in this study are given in Eq. 11.

$$IF\ input_1\ is\ \tilde{B}_{j1}, and\ input_2\ is\ \tilde{B}_{j2}, \ldots, and\ input_m\ is\ \tilde{B}_{jm}\ THEN\ output_j = \sum_{i=1}^{m} \omega_{ij} input_i + b_j \tag{11}$$

In this equation; $\tilde{B}_{ij}$ are type-2 membership functions for the j*th* rule belonging to i*th* input, ω_{ij} and b_j are type-1 fuzzy parameters.

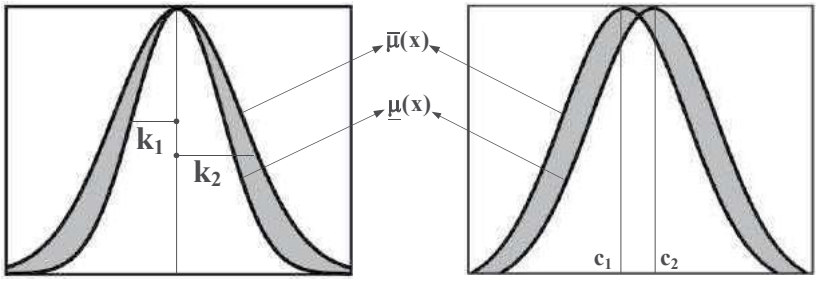


Figure 2. Gaussian type-2 fuzzy membership function

As shown in Fig. 2, Gaussian type membership function is preferred in this study. The mathematical equation of Gaussian membership function is presented as:

$$\mu(x) = exp\left(-\frac{1}{2}\frac{(x-c)^2}{k^2}\right) \tag{12}$$

Where; k presents centre of Gaussian membership function and c presents width of Gaussian membership function. In this study, one of the k or c are assumed to be uncertain. However, training rules are considered for both cases [18]. Structure of the T2NFC used in this study is depicted in Fig. 3. The layer-1 of T2NFC distributes inputs. Layer-2 presents linguistic term. In this layer, membership degrees are computed for each input signal. The product operation are performed in layer-3. Outputs of the linear functions are determined in layer-4. The product of membership degrees is computed in layer-5. Layer-6 contains two summation blocks. The output of T2NFC are computed in Layer-7. The learning rate is an important parameter for the backpropagation algorithm to be able to approximate global minima. Learning rate with big value can bring out stability problem whereas its small value can cause to slow learning and local minimum problem [16-18]. As the learning rate is determined, adaptive methods can be used. The learning rate is usually chosen in the range [0, 1] and this value is chosen as 0.05 in this study

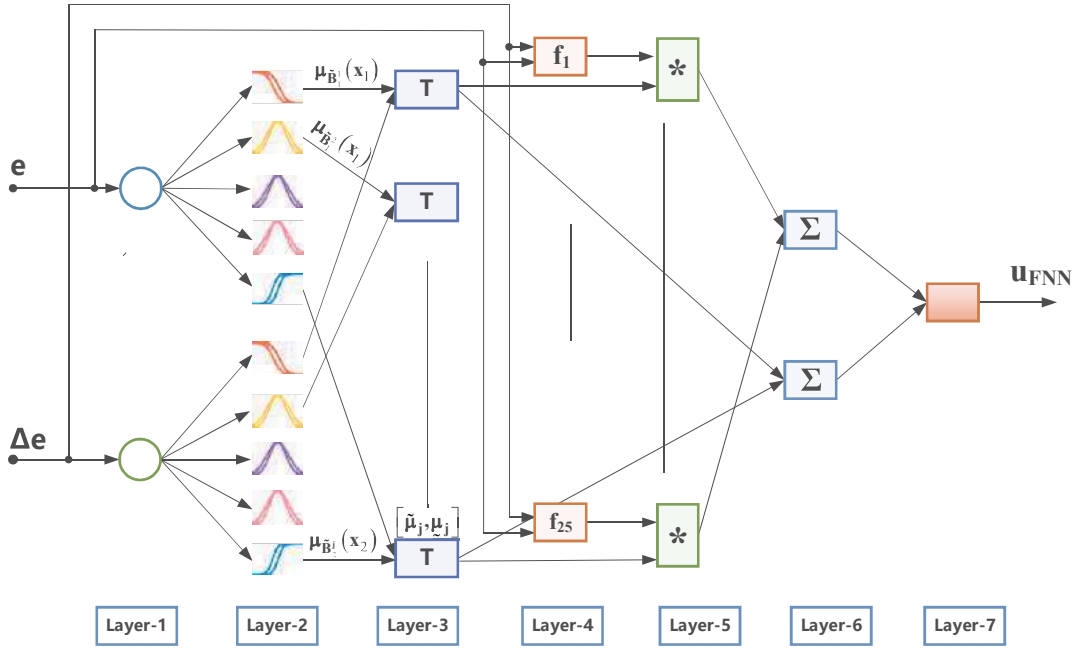


Figure 3. Internal structure of T2NFC

4. SİMULATION STUDIES

In this study, simulation study is carried out to indicate performance of SAPF with proposed controller. As seen from the Fig. 4, the developed SAPF model consists of three-phase source, two-level inverter, nonlinear load, control and measuring units. Also, Inner structure of SAPF block is given in Fig. 5. The parameter values of SAPF and non-linear load are given in Table 1. PI controller and T2FNNC are designed for DC bus voltage control of SAPF model and two tests are conducted for these two controllers under the same conditions. The gain parameters of PI controller are found as K_p=0.12, K_i= 4. In addition, the Gaussian membership function is preferred for the controller structure proposed in this study.

Test 1: This test is conducted to assess the performance of SAPF with proposed controller under the steady-state condition. The waveform related with this test are given in Fig. 6. Figure 6 consists of three-phase grid currents, load currents, compensating currents and DC-bus voltage. To compensate the harmonics which produced by non-linear load, the switch is activated at t = 0.1 s. With compensation, three-phase grid currents have become sinusoidal. As can be seen in Fig. 6, the DC bus voltage is set to 220 V and the oscillation in DC bus is very low. Before compensation, the power factor of the system is measured to be approximately 0.78. In addition, the total harmonic distortion of the grid current is 23%. After compensation, the power factors of SAPF with PI and T2FNNC are 0.99 and 0.995, respectively. THDs of both controllers are 1.5% and 1.39%.

Test 2: This test is conducted to evaluate the behavior of SAPF with two controllers under the transient condition. Transient condition is created by load change. The waveform of three-phase grid currents, load currents and compensating currents and DC-bus voltage of SAPF in this test are given in Fig. 7. First, the system has a fixed load. Then load is changed at t=0.15 s. Finally, the load is removed from the system at t=0.35 s. Fig. 7 shows that the grid current has increased during the increase of the load current. When the load is removed from the system, the gird and load currents returns to their original value. It is observed from this test condition that DC-link voltages of SAPF with PI and proposed controllers are balanced to their reference value after 1.25 s and 1.8 s, respectively. As can be clearly observed in this test, the proposed controller based SAPF has better dynamic performance than PI controller.

Table 1. Electrical parameters of SAPF

Parameters	Values
Grid Voltage (V_s)	80 V
DC bus Capacitor (C)	1.2 mF
Source impedance (R_s, L_s)	0.1 mΩ, 0.1 mH
Filter impedance (R_f, L_f)	0.1 mΩ, 0.1 mH
Diode rectifier load (R,L)	60 Ω, 20 mH
Load (R, L)	180Ω, 10mH
Sampling Time	50 µs
PI Controller	K_p=0.12, K_i=4

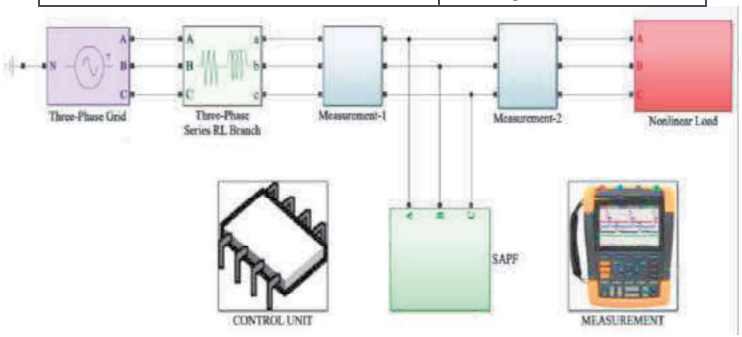


Figure 4. Simulation model of SAPF

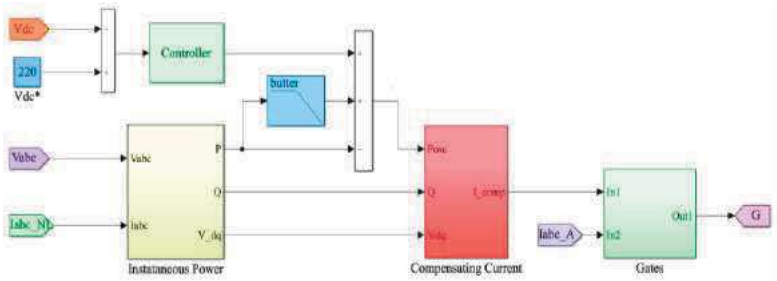
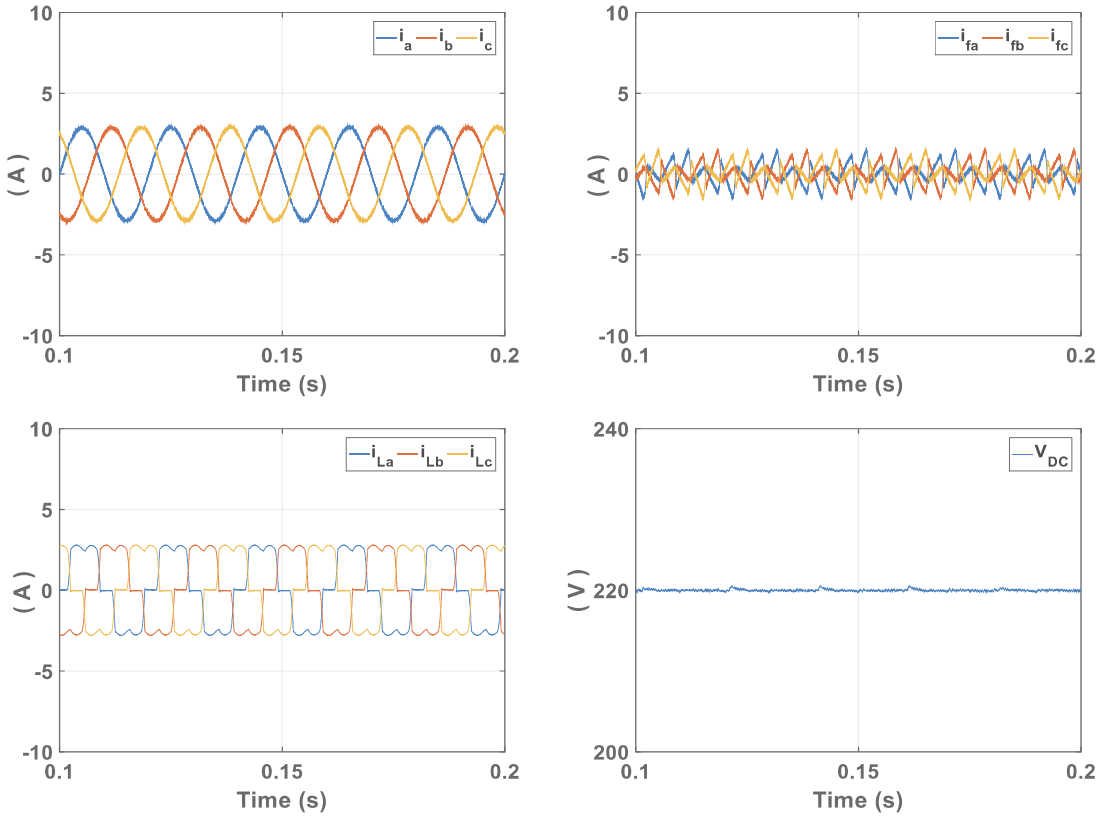
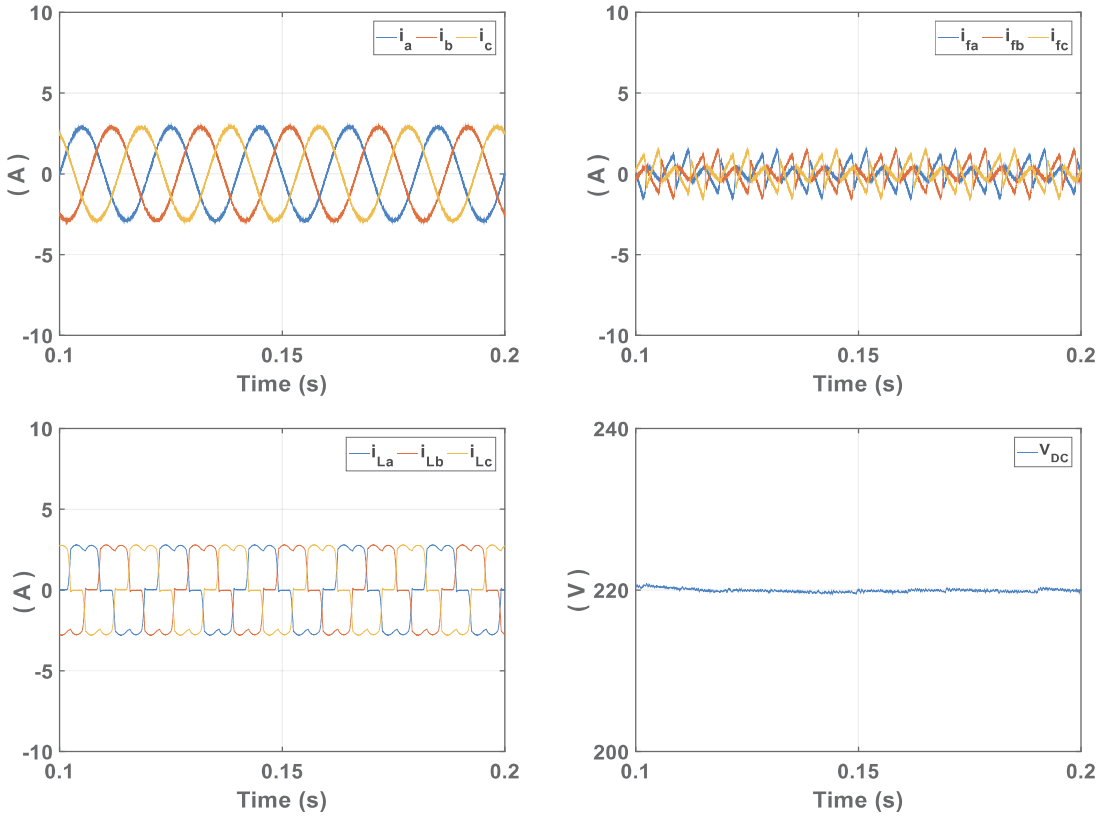


Figure 5. Inner of SAPF block

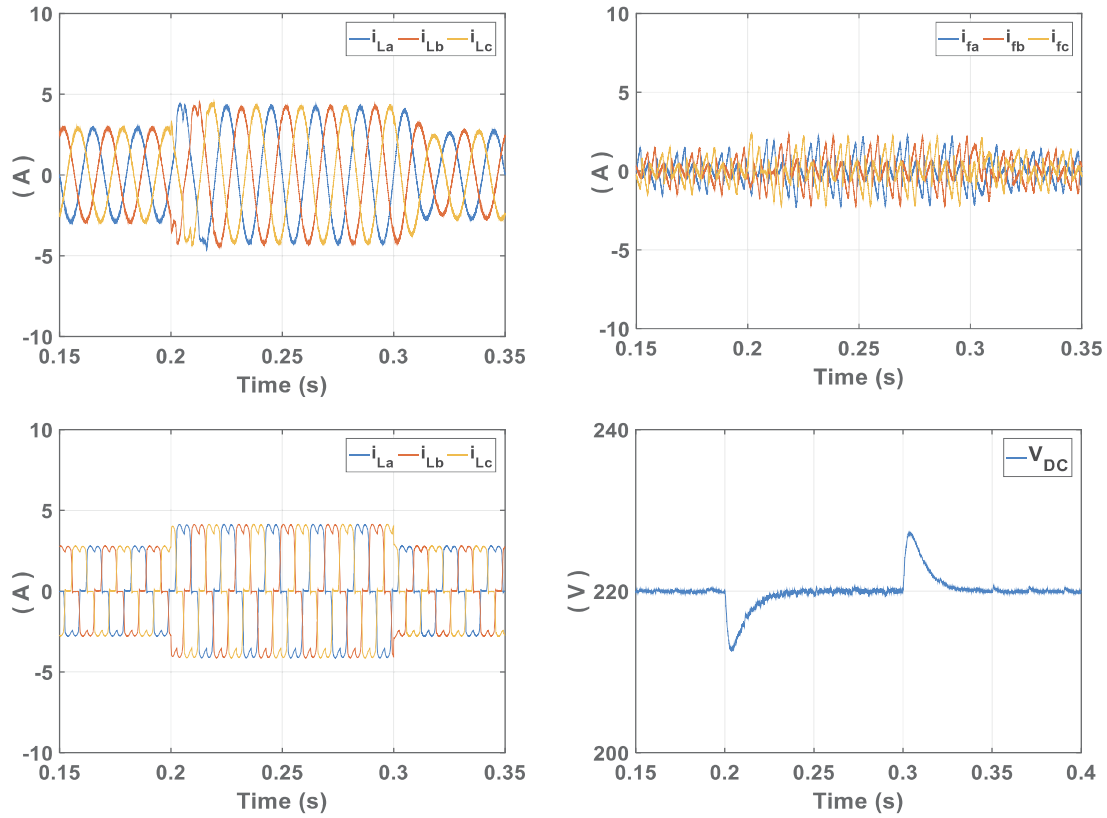


(a)

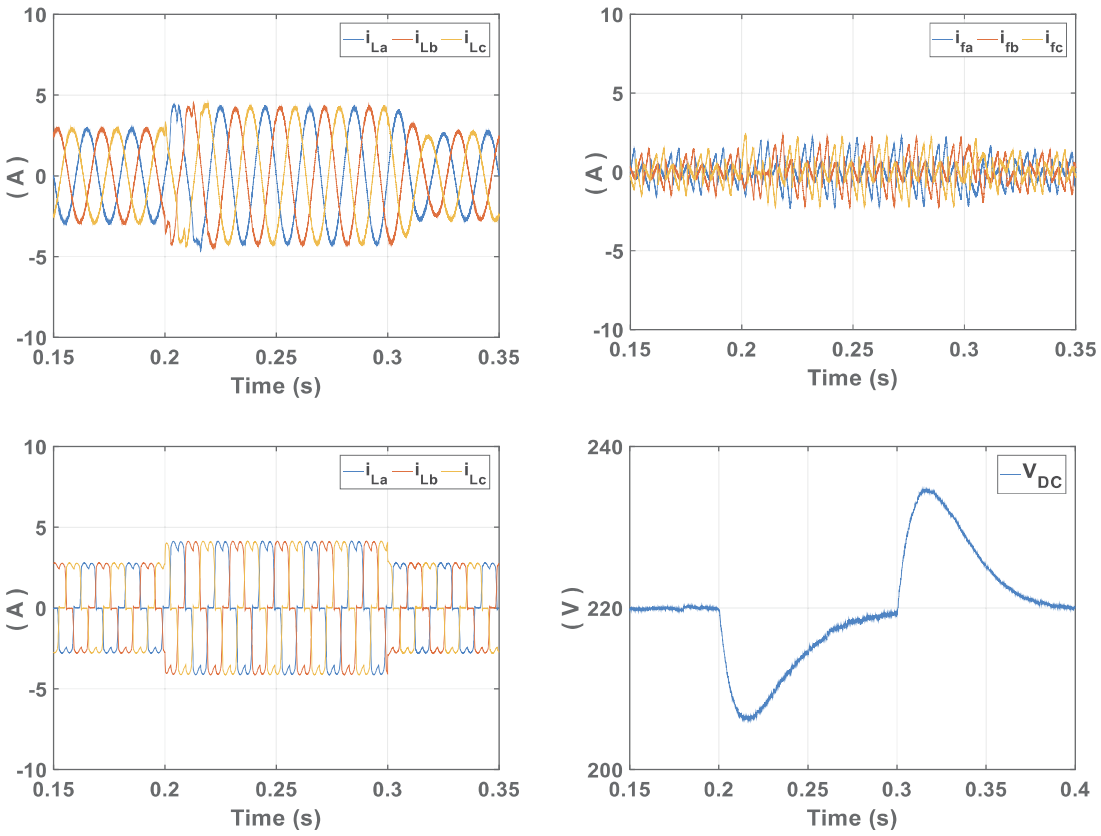


(b)

Figure 6. Waveforms of SAPF for Test 1 a) T2FNNC b) PI Controller



(a)



(b)

Figure 7. Waveforms of SAPF for Test 2 a) T2FNNC b) PI Controller

5. CONCLUSIONS

In recent years, many studies have been carried out to improve the dynamic performance of shunt active power filters. This paper presents the performance results of SAPF based on a novel controller. Type-2 fuzzy neural network controller, which has a superior structure against the uncertainties, has been proposed for controlling the DC-link voltage of SAPF. The main purpose of proposed controller is to improve the robustness of SAPF against to disturbances and uncertainties. In addition, the performance of the proposed controller is compared to PI controller. Two simulation tests are conducted for both controller structures under the same conditions. The simulation studies have been clearly demonstrate that the performance of the proposed controller based SAPF structure has been improved in transient and steady-state conditions. Moreover, the control of DC-link voltage of SAPF has been performed perfectly with proposed controller. The THD of the grid current is reduced and the energy quality of SAPF is improved.

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