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Control of dc capacitor voltage in active power filters

Abstract. *The paper deals with the three-phase three-wire shunt active power filter. The analysis of capacitor voltage in such compensator is presented. It is shown that fast component of the capacitor voltage is unavoidable. The slow component should be stabilized on the desired level. The results of SIMULINK computation for chosen structures of the compensator are presented in the paper. Two controllers of capacitor voltage are treated – PI controller and fuzzy logic controller.*

Streszczenie. *W pracy zaprezentowano analizę napięcia kondensatora w trójfazowym aktywnym filtrze energetycznym w układzie trójprzewodowym. Pokazano, że obecność składowej szybkiej napięcia kondensatora jest niezbędna, gdyż wynika ona z istoty wymiany energii w takim układzie. Składowa wolna napięcia powinna być stabilizowana na założonym poziomie. Przedstawiono przykładowe wyniki obliczeń z zastosowaniem programu SIMULINK dla wybranych struktur kompensatora. Zbadano dwa rodzaje regulatora napięcia kondensatora – regulator PI oraz regulator rozmyty.* ***(Sterowanie napięcia kondensatora w energetycznych filtrach aktywnych)***

Keywords: active power filters, dc capacitor voltage, dc voltage controller.
Słowa kluczowe: energetyczne filtry aktywne, napięcie kondensatora dc, regulatory napięcia dc

Introduction

The three-phase three-wire shunt active filter using three-leg voltage source converter (Fig. 1) is considered in the paper.

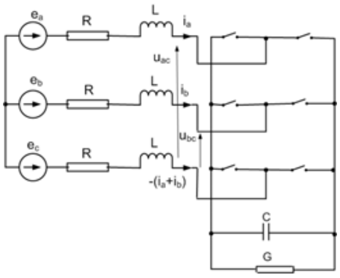

Fig. 1. Structure of three-phase three-leg active filter

Active filtering is one of the most challenging applications for digital current controls. But proper design of passive components of the active power filters (APF) also plays important role [1].

The value of dc capacitor can be selected on the basis of load power rate and the ability to operate switching of the voltage source inverter. Capacitors are used as a source of energy to generate reactive power and eliminate harmonics . The bigger energy storage is needed in the dynamic voltage restorer aimed on the voltage sag reduction. Thus, in such application the capacitor needs to supply active power within a limited time interval.

Analysis of the capacitor voltage

Let the average value of compensating currents i_a and i_b of the three-phase, three-wire circuit, shown in Fig. 1 be given. Voltage u_C can be computed from energy balance. If the inverter losses are omitted the power drawn by the inverter is equal zero for each time instant *t*

$$u_{ac}i_a + u_{bc}i_b = u_C i_C \tag{1}$$

where

$$u_{ac} = e_{ac} - 2L\frac{di_a}{dt} - L\frac{di_b}{dt} - 2Ri_a - Ri_b \tag{2}$$

$$u_{bc} = e_{bc} - 2L\frac{di_b}{dt} - L\frac{di_a}{dt} - 2Ri_b - Ri_a \tag{3}$$

$$i_C = C\frac{du_C}{dt} + Gu_C \tag{4}$$

Substituting equations (2), (3) and (4) into (1) the differential equation determining searched voltage u_C is obtained

$$\frac{du_C}{dt} = \frac{1}{C}p(t){u_C}^{-1} - \frac{G}{C}u_C \tag{5}$$

where $p(t) = u_{ac}i_a + u_{bc}i_b$.

Example

Equation (5) has been solved for the following circuit parameters: L=0.01 H, C=50 μF, R=1 Ω, G=0.0005 S.

The three-phase generator is symmetrical and $e_a = E_{m1}\sin(\omega t)$, $E_{m1} = 600$ V. Let the reference compensator current is symmetrical and contains first and fifth order harmonic $i_a = I_{m1}\sin(\omega t) + I_{m5}\sin(5\omega t)$, $I_{m1} = 1.5$ A, $I_{m5} = 20$ A. Initial capacitor voltage $u_C = 1000$ V.

The simulation result is shown in Fig. 2.

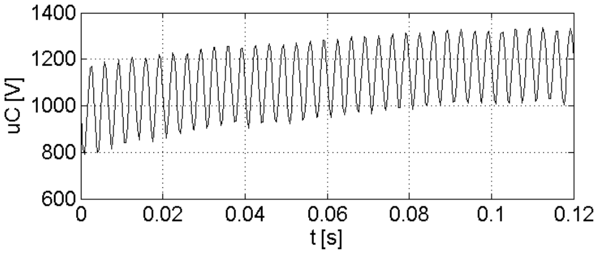

Fig. 2. Example of capacitor voltage waveform

There are two phenomenon governing the dc capacitor voltage changing (Fig. 3). The slow voltage increasing (or decreasing) is the effect of energy losses in the APF and the active power delivering to the APF by the fundamental current harmonic. The second kind of voltage change have waving shape. This kind of voltage waving, it the effect of the energy exchanging between the load and filter capacitor. The slow component of the capacitor voltage should be stabilized. The second component is unavoidable, it plays the essential role in the filtering. It is the result of instantaneous power exchanging between the dc capacitor, interface inductor and supplying grid. The magnitude of this wave depends on a capacitance value. It depends also on magnitude and frequency of the filtered current. The correlation between power $p(t)$ and capacitor voltage $u_C(t)$ can be observed in Fig. 3. The results have been obtained for 5th order harmonic (Fig 3a) and 13th order harmonic (Fig. 3b). The magnitude of fundamental harmonic is $I_{m1} = 1.3$ A, the remaining parameters were the same as given in the example presented above. Fig. 3c shows the instantaneous power and capacitor voltage for reference current equal $i_a = 0.5\sin(\omega t) + 4\sin(\omega t + \pi/2)$.

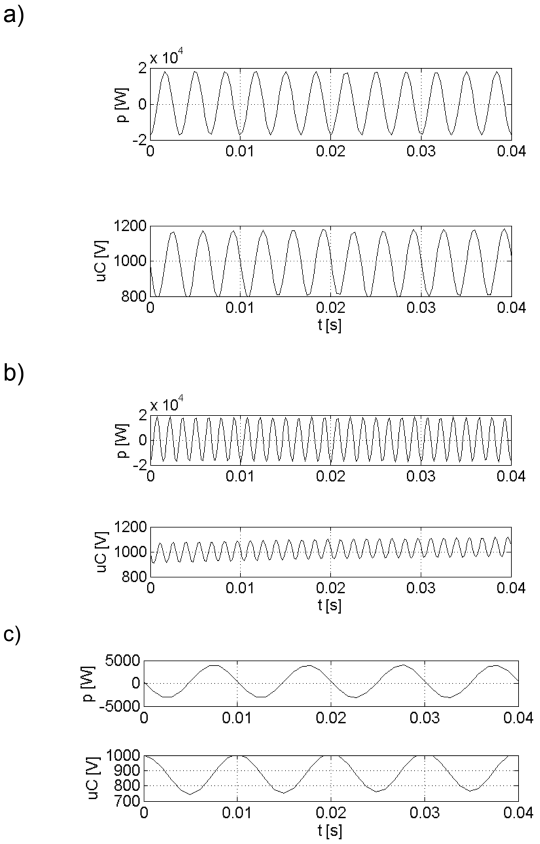

Fig. 3. Power exchanging between the grid and dc capacitor: a) 5th order harmonic of reference current, b) 13th order harmonic of reference current, c) reactive fundamental harmonic of reference current

Simulation results

In a real implementation, a dc voltage regulator must be present to keep the dc voltage around its reference value. The controller must act as a low-pass filter in order not to interfere in natural power exchanging which guaranties the reference current flow. The paper presents the simulation results of the APF with different realizations dc capacitor controllers.

Fig. 4 shows the model of three phase shunt active power filter with power converter simulated with the use of SIMULINK.

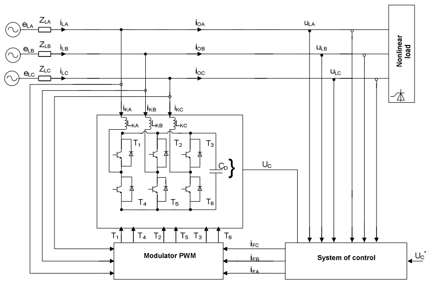

Fig. 4.Three-phase three-wire shunt active filter

The numerical parameters of the system are given in table 1.

Two controllers of dc voltage have been considered – PI controller and fussy logic controller. For both cases hysteresis-based current control and δ controller have been applied. The numerical parameters of the system are given in table 1 and 2.

Table 1. Supplying system and controller parameters

Amplitude of voltage supplied network in phases A, B, C	325V
Frequency of the supplied network voltage	50Hz
Shift phase between A, B, C voltages	120°
Inductance of the supplied network	1mH
Resistance of the supplied network	10m Ω
Inductance of the filter	6mH
Resistance of the filter	1m Ω
Active shunt filter capacitor	490uF
Voltage reference for active shunt filter	795V
Internal resistance of IGBT transistor/diode	0,01Ω
Controller PI	P=1, I=0.01

There are two input signals in the fussy controller (Fig. 5).

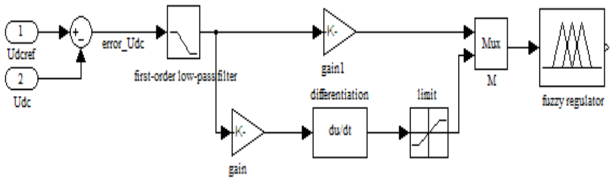

Fig. 5. Fuzzy control diagram of the capacitor voltage

Two signals are processed in the Mamdani's fussy system (Fig. 6). The difference between the desired and actual capacitor voltage is one of this signal, the derivative of this signal is the second signal. These both signals are taken with proper weight. The differential signal is additionally limited in order to reduce a noise and prevent oscillations.

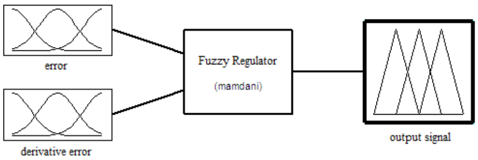

Fig. 6. Block diagram of the Mamdoni fuzzy system

The membership function for input signal of the voltage capacitor error is composed of three functions illustated in Fig. 7.

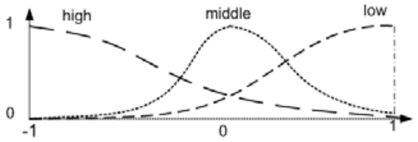

Fig.7. Membership functions defined for the input signal of the error

The membership function for input signal of the voltage capacitor error dervative is composed of two functions illustrated in Fig. 8.

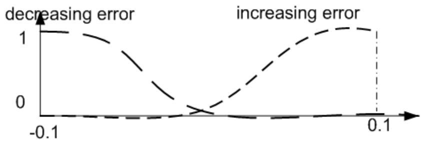

Fig. 8. Membership functions defined for the input signal of the error derivative

The membership function for output signal of the voltage capacitor control is composed of five functions illustrated in Fig. 9.

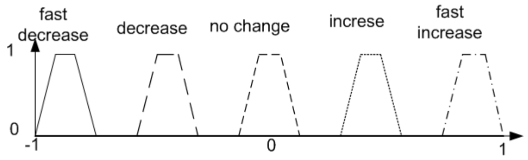

Fig. 9. Membership functions defined for output signal

For the fuzzy controller is governed by two rules - conjugation and implication in the following manner: if error is on low level the output signal is fast increased, if error is on high level the output signal is fast decreased, if error is mid level the output signal remains without change, if error is on mid level and its derivative is negative the output signal is slowly increased, if error is on mid level and its derivative is positive the output signal is slowly decreased.

The example of the waveforms obtained in the simulation process is shown in Fig. 10. The higher drawing shows the waveforms in the steady state for time interval (0.4s, 0.5s) and the transient of these waveforms are shown in the lower drawing for time interval (0-0.1s).

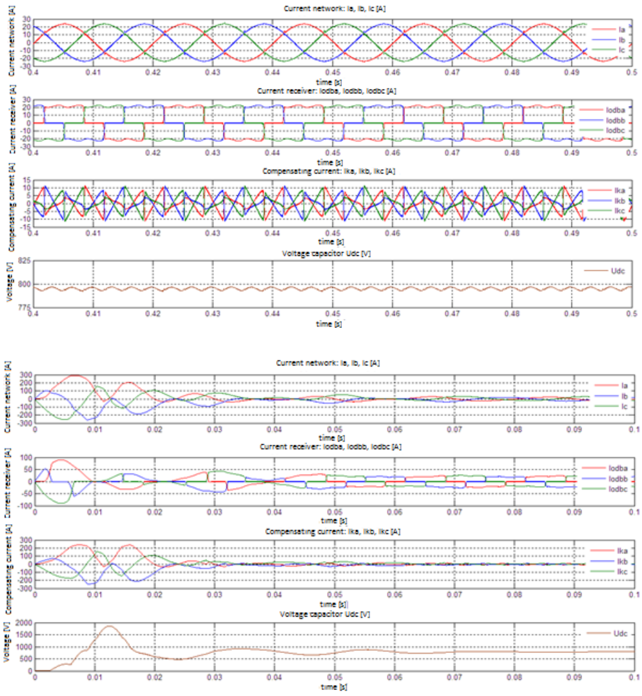

Fig. 10. Example of the simulation results

The example of the harmonic spectrum of the line current after compensation is shown in Fig. 11.

Few compensation parameters for PI and fuzzy logic controllers are compared in Table 2. These results have been obtained for the compensator with hysteresis controller, as the load the resistance rectifier has been chosen.. For the compensator with σ-controller results are similar. The maximum of the currents are observed in transients. THD were computed for steady state currents.

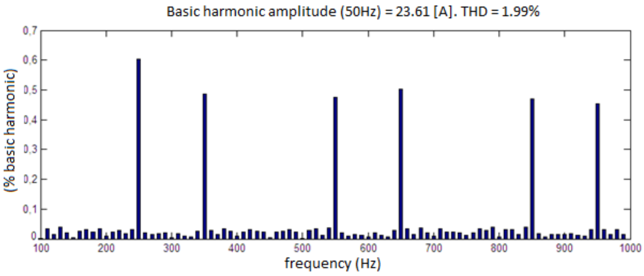

Fig. 11. Fourier transform of the line current after compensation

Table 2. Comparison of two controllers

Controller	THD of the line current	Maximum of the line current	Maximum of the compensator current
PI	3.21	300A	270A
Fuzzy logic	3.05	120A	100A

Conclusions

The capacitor voltage waveform contains two component: fast component and slow component. The fast component is the result of energy exchanging between the supplying grid and compensator while the desired harmonics are generated. This component is unavoidable during compensation process. The slow component should be reduced in order to maintain the capacitor voltage on a desired level. The capacitor voltage can be stabilized with the use of a PI or fuzzy logic controller.

The fuzzy logic controller is more flexible than PI controller. This controller gives more possibilities to shape the compensator current waveform during the transient. The current peaks can be maintained on the desired level. It is achieved owing to the control of not only the capacitor voltage error but also the derivative of this error.

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