INFLUENCE OF INPUT INDUCTANCE OVER DYNAMIC CHARACTERISTICS OF SINGLE-PHASE SHUNT ACTIVE POWER FILTER

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This paper presents the influence of input inductance over dynamic characteristics of a single-phase active power filter. Mathematical description is made and relationship among filter inductance, response time and other parameters of the system load – active power filter is derived. 3D graphics built using found formulas, simulation and experimental results are presented.

Keywords: input inductance, active power filter.

1. INTRODUCTION

Different methods to control shunt active filters are known – some of them are as follows: hysteresis-current control [1] [2], PI-control [3] [4], PWM control [4], fuzzy logic [5], genetic algorithms [6] [7], predictive control [8], control based on p-q theory [5], neural network [9], the method of "the equivalent" sinusoid [10]. Dynamic characteristics of the active power filters depend not only on the chosen control method but also on the value of the input inductance.

Possibilities for fast reaction of the active power filter (APF) under sharp changes of the load current, especially under periodical changes, are of a significant importance using hysteresis current control and tracing of a reference current waveform. The aim of this paper is to study the influence of input inductance of the filter over its dynamic characteristics.

2. DESCRIPTION OF THE FILTER

Fig.1 presents a block schematic of the filter, its control system and signal feedbacks. Monitoring the source voltage u_S and the load current i_L in each period is followed by calculation of the consumed active power and effective value of the source voltage. Their devision leads to the amplitude of "the equivalent" sinusoid I'_m corresponding to the consumed current after a connection of APF [10]. This value is multiplied by an output value of a digital PI regulator used to maintain constant the capacitor voltages V_{dc1} and V_{dc2}. Then a reference sinusoid in phase with the source voltage is generated in digitals. The values of the sinusoid are compared with current values of the source current i_S by a hardware system for a hysteresis – current control. The output of the comparison is the logical signal to control the power switches as follows – turning on the VT1 increases the current and turning on VT2 decreases it. Fig.1 also shows the system for an initial adjustment of the control program.

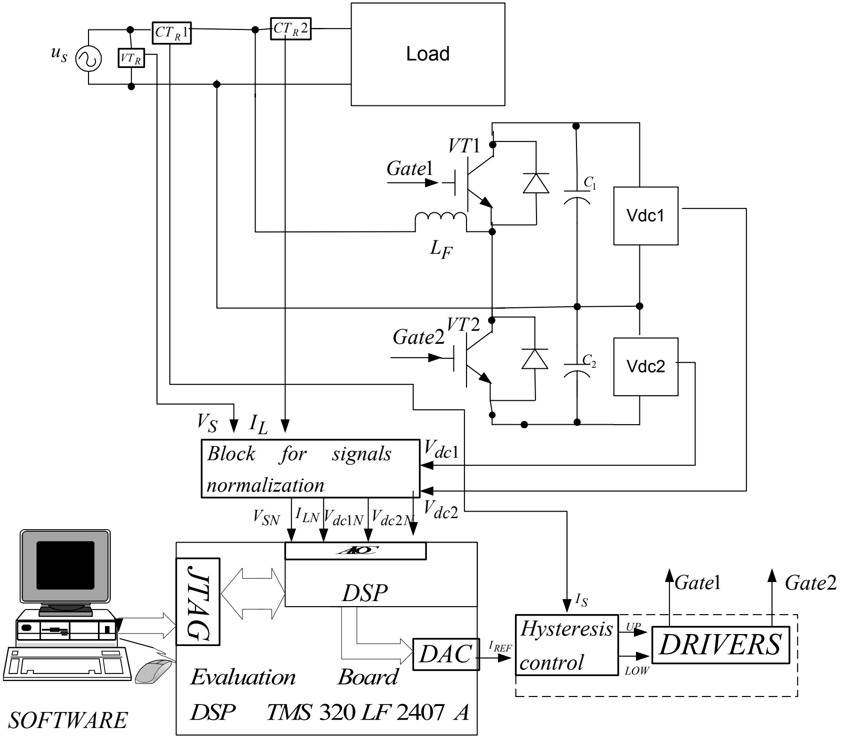


Fig.1. Block-schema of the filter

3. MATHEMATICAL DESCRIPTION

Fig.2 shows basic quantities characterizing the system operation, when an APF is connected to the system supply network – load (uncontrolled rectifier with an active-inductive type of load). In the beginning of each half-period, there is a sharp change into the load current and in this moment, the filter should react as fast as possible.

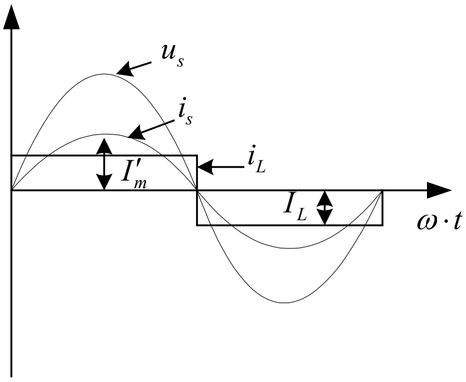


Fig.2. Source voltage of the supply network u_S, source current consumed by system APF – rectifier i_S, input current of the rectifier i_L

The following equations are known for the filter current, the corrected total source current and the examined load current [2]:

$$i_F = \frac{u_s \pm U_d}{R_F} \cdot \left(1 - e^{-t\frac{R_F}{L_F}}\right), \quad i_S = I'_m \cdot \sin(\omega \cdot t), \quad i_L = \pm I_L \tag{1}$$

It is also known that when using APF, the total power S_{APF} consumed by the load and the filter is equal to the active power P_{NAPF} consumed only by the load:

$$P_{NAPF} = \frac{U_{Sm}}{\sqrt{2}} \cdot I_L = S_{APF} = \frac{I'_m}{\sqrt{2}} \cdot \frac{U_{Sm}}{\sqrt{2}} \tag{2}$$

Equation (2) leads to:

$$I'_m = \sqrt{2} \cdot I_L \tag{3}$$

The dependence among the filter current and the load and the source currents is:

$$i_F = i_S - i_L \tag{4}$$

Using equations (1), (3) and (4) for the beginning of a period the following relation is valid:

$$i_F = \frac{\pm U_{Sm} \cdot \sin(\omega \cdot t) - U_d}{R_F} \cdot \left(1 - e^{-t\frac{R_F}{L_F}}\right) = \pm I'_m \cdot \sin(\omega \cdot t) \mp I_L = \pm I_L \cdot \left(\cdot \frac{4}{\pi} \sin(\omega \cdot t) \mp 1\right) \tag{5}$$

From (5) the input filter inductance is derived as follows:

$$L_F = \frac{-t \cdot R_F}{\ln\left[1 - \frac{R_F}{\pm U_{Sm} \cdot \sin(\omega \cdot t) - U_d} \cdot \pm I_L \cdot \left(\frac{4}{\pi} \sin(\omega \cdot t) \mp 1\right)\right]} \tag{6}$$

A 3D graphic using Mathematica4.1 software presents the relationship among the filter inductance, the output current of the load and the time to reach the desired value of the filter current after the beginning of each half-period, is presented at Fig.3A. This graphic is made with maximum value of the source voltage $U_{Sm} = 310V$ and its frequency $f = 50Hz$. Filter capacitors voltages are maintained to $U_d = 360V$.

If the desired current value is achieved after the beginning of a half-period, then there is a need to secure stability from the point of view of sliding-mode control theory when using hysteresis-current tracing. As only the current is monitored, the mathematical system is a first-order system as follows:

$$\dot{x} = f(x) + b(x) \cdot u \tag{7}$$

where in $x = i_F$, $b(x) = 1$, $u = u_s \pm U_d$ and $f(x) = -\frac{R_F}{L_F} \cdot x = -k \cdot x$

The error of the tracing presented in the sliding mode theory is:

$$\dot{\tilde{x}} = \dot{x} - \dot{x}_d = \dot{i}_F - \dot{i}_d \tag{8}$$

Using the above mentioned theory and equations (1) and (5), it is derived the following equation for the error, after the sliding surface has been reached:

$$\tilde{\dot{x}} = \dot{i}_F - \dot{i}_d = \frac{\omega \cdot U_{Sm} \cdot \cos(\omega \cdot t)}{R_F} \cdot \left(1 - e^{-t\frac{R_F}{L_F}}\right) + \frac{U_{Sm} \cdot \sin(\omega \cdot t) \pm U_d}{L_F} \cdot e^{-t \cdot \frac{R_F}{L_F}} \mp \omega \cdot \frac{4}{\pi} \cdot I_L \cdot \cos(\omega \cdot t) \quad (9)$$

This equation is used to find the control of the first-order system corresponding to the sliding-mode theory, a 3D graphic is made using Mathematica4.1 software, and it is presented at Fig.3B.

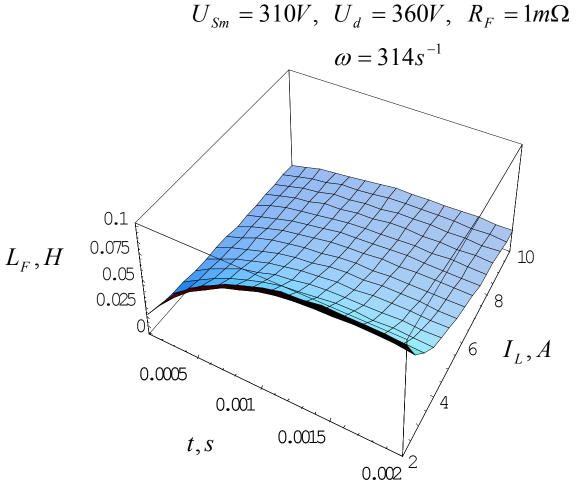


Fig.3A. Graphical relationship built form equation (6)

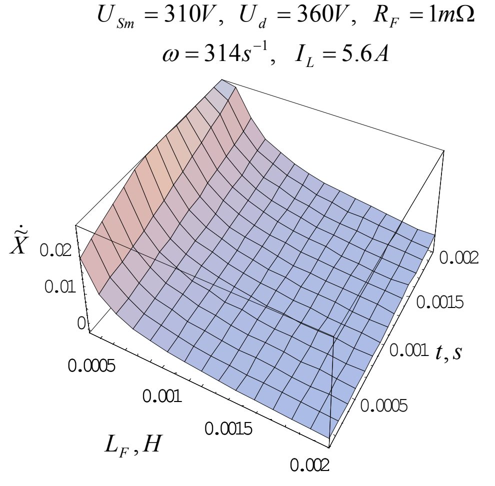


Fig.3B. Graphical relationship built form equation (9)

4. COMPUTER SIMULATION

Computer simulation of the operation of the system supply network – APF – uncontrolled rectifier is made by the use of MicroSim8.0. The results are shown at Fig.4.

The parameters of the studied system are $U_{Sm} = 310V$, $U_d = 360V$, $L_f = 2.5mH$ and $I_L = 5.7A$.

5. EXPERIMENTAL STUDY

Experimental study is made upon the operation of a single-phase shunt active power filter. In this study, the filter is implemented using half-bridge power schematic. To monitor the source current, load current and source voltage, two current and one voltage transducers produced by LEM are used, LA-55A and LV25-P, respectively. The elements of the active power filter are: transistros MII-100 produced by IXYS, filter inductiveness $L_f = 2.5mH$, filter capacitors 2 pieces $C_f = 3900\mu F$. The parameters of the uncontrolled rectifier are the same as these used during simulation study.

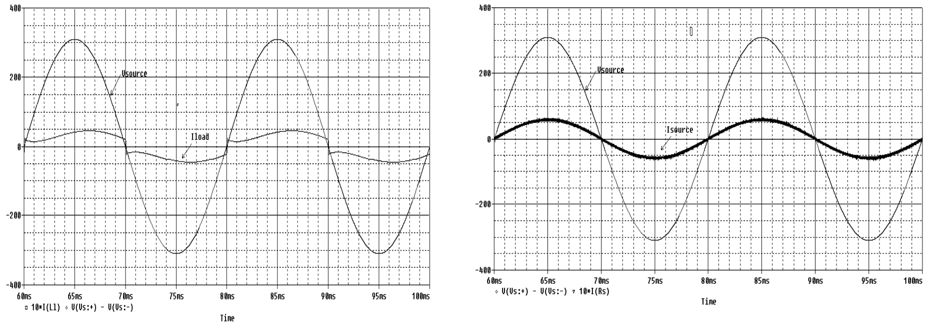
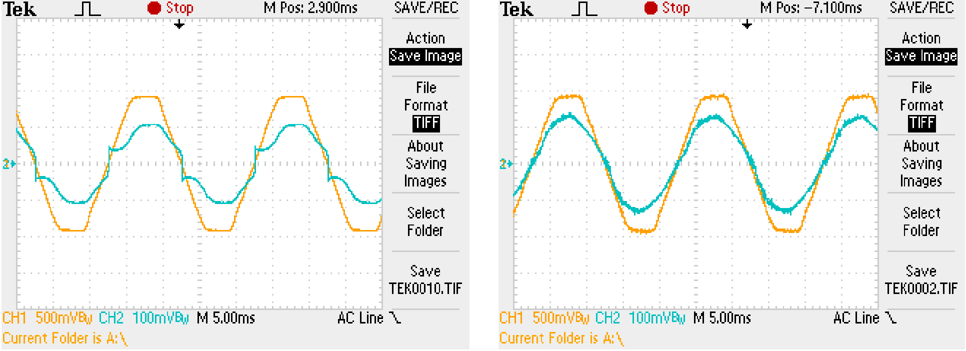


Fig.4. Simulation results that present source voltage and consumed current, when nonlinear load, is connected to the supply network. On the left – APF is not turn on, on the right – APF is turned on.

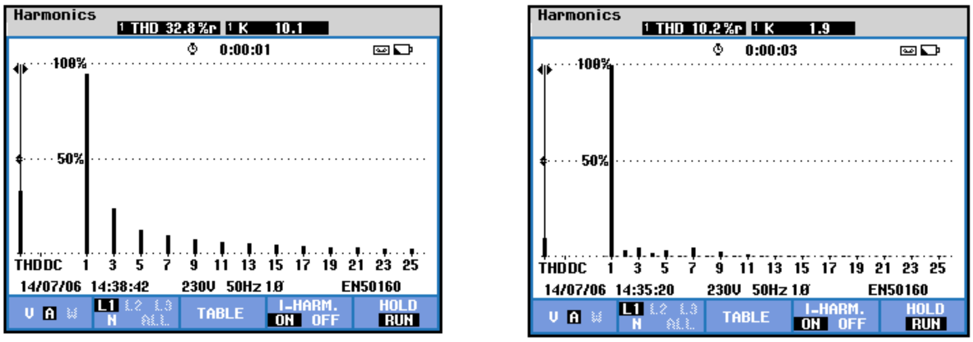
Fig.5 shows oscilograms characterizing the operation of the uncontrolled rectifier, and the operation of the system load – APF.

Harmonics spectrum of the source current when the APF is not connected to the system load-source network and when it is connected to the system is shown on Fig.6.A and Fig.6.B, respectively.



A B

Fig.5. A. Source voltage and source current, when APF is not connected. B. Source voltage and source current, when APF is connected



A B

Fig.6. A. Harmonics spectrum of the source current when the APF is not connected. B.Harmonics spectrum of the source current when the APF is connected

6. CONCLUSION

Design of the input inductance of the active power filter requires a complex approach and the found equations in this paper, proved to be effective, are of a great importance. The simulation and experimental results show very good dynamic response of the active power filter and a sufficient tracing of the reference signal when filter inductance is chosen with accordance to the found formulas in the paper.

7. ACKNOLEDGMENT

The study carried out in this work is made in connection with Contract VU – TN – 116, between the (RDS) TU – Sofia and the Ministry of Education and Science Bulgaria.

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