MATLAB/SIMULINK LIBRARY FOR COMPENSATING CURRENT CALCULATION IN THREE-PHASE SHUNT ACTIVE FILTERING SYSTEMS

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REZUMAT. Într-un sistem de filtrare activă paralel, componenta circuitului de control care implementează strategia de compensare adoptată este blocul de generare a curentului de referinţă, ce trebuie compensat. În această lucrare, este prezentată o bibliotecă Matlab/Simulink pentru generarea curentului de referinţă în cazul compensării totale şi al celei parţiale, bazată pe conceptele principalelor teorii ale puterilor în regim deformant. Aceasta este utilizată în implementarea sistemului de control pe o platformă experimentată dSPACE.

Cuvinte cheie: filtre active, modelare, biblioteci software, sisteme de comandă şi control.

ABSTRACT. In a shunt active filtering system, the component of the control circuit which implements the adopted compensation strategy is the reference compensating current generation block. This paper presents a Matlab/Simulink library for compensating current generation in case of both total and partial compensation, based on the concepts of the main theories of the powers under nonsinusoidal conditions. It is used in the implementation of the control system on an experimental dSPACE platform.

Keywords: active filters, modeling, software libraries, command and control systems.

1. INTRODUCTION

In power systems containing non-linear loads, especially those using static converters, the power quality improvement by active filtering is the versatile solution leading to the best performance because of its capabilities. Indeed, the flexibility in controlling the voltage source inverter of the active power filter allows the implementation of any compensation strategy, whereas the recent evolution of power switching devices and digital control systems guarantee a grid current after compensation which is very close to both the desired waveform and phase angle [1]-[3].

In a shunt active power filtering system (SAPFS), the inverter which is connected to the point of common coupling through an interface passive filter has the task to draw an appropriate controlled-compensating current required by the compensation strategy.

The main part of the control circuit in SAPFS is the reference compensating current calculation based on distorted load currents. When complex compensation strategies are taken into consideration, such as reactive power compensation or unity power factor control, the supply voltages are also needed to generate the compensating currents. After generating the reference currents, a key issue is the current-control strategy to adequately track the calculated values.

Most of SAPFS implementations make use of the current decomposition in relation to the power flow [4]-[8]. Thus, the current to be compensated can be easily identified and calculated in accordance with the compensation objective. However, when the compensation goal is to impose the current drawn from the power supply, a simpler solution is to calculate the compensating current by subtracting the desired supply current from the distorted load current.

In this paper, a Matlab/Simulink library for time-domain-based reference compensating current calculation is presented. One of the objectives is to achieve a comparative analysis of the calculation methods. Moreover, this library is part of an experimental dSPACE platform for rapid prototyping developed by authors for the DSP-based implementation of the SAPFS control.

2. CASCADE CONTROLLED SAPFS

In the three-phase three-wire SAPFS shown in Fig. 1, the reference current calculation block generates the desired compensating currents i_{FCa}, i_{FCb} and i_{FCc} in accordance with the compensation strategy by using the load currents and supply voltages.

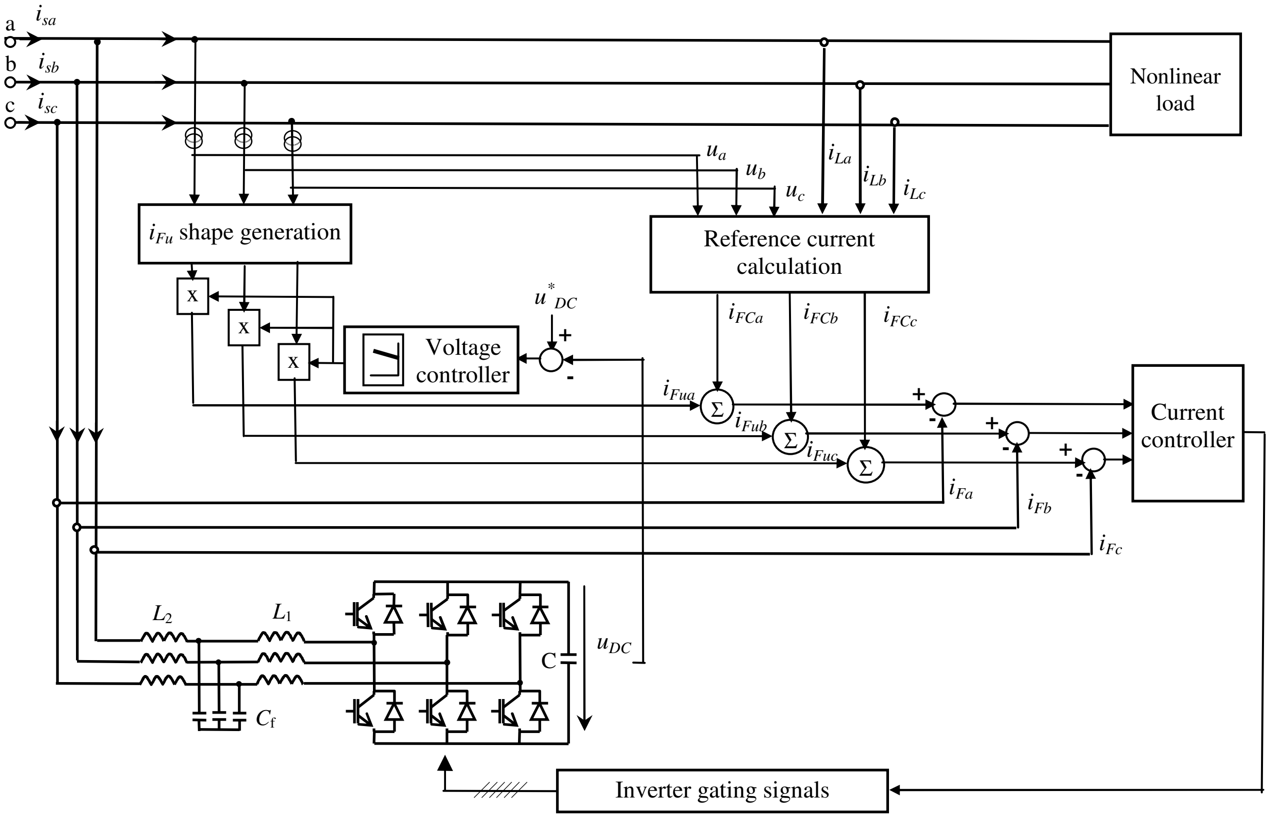

Fig. 1. Cascade control of a three-phase three-wire SAPFS.

As the inverter needs additional active currents to cover the power losses and keep the DC-side inverter voltage at its set value, an external voltage loop provides the additional components i_{Fua}, i_{Fub} and i_{Fuc} of the currents to be tracked. Usually, a proportional integral (PI) voltage controller is adopted in the voltage loop. As regards the current controller, several techniques, such as PI, hysteresis-band, deadbeat and nonlinear control can be implemented [9]-[11].

3. MATLAB/SIMULINK LIBRARY FOR REFERENCE COMPENSATING CURRENT CALCULATION

The time-domain techniques taken into consideration in the reference current calculation stage of the control system are grouped into two categories, either phase coordinate system–based methods or orthogonal reference frame–based methods, according to the coordinate system in which calculations are made. As shown in Fig. 2, whatever the adopted method, the reference current calculation block has six inputs (phase supply voltages and load currents) and six outputs (phase compensating currents and supply currents after compensation).

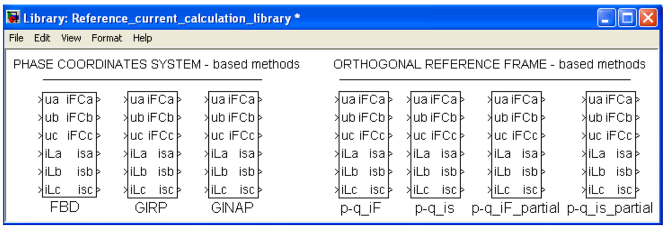

Fig. 2. Structure of the Matlab/Simulunk library

a) Fryze-Buchholz-Depenbrock theory– based block

The Fryze-Buchholz-Depenbrock (FBD) theory allows expressing the phase active currents [5],

$$i_{ka} = G \cdot u_k\,, \quad k = a, b, c \tag{1}$$

through an equivalent conductance defined as

$$G = \frac{P_\Sigma}{\left\| u_\Sigma \right\|^2}\,, \tag{2}$$

where P_Σ is the collective active power and $\left\| u_\Sigma \right\|$ is the collective rms voltage given by:

$$P_\Sigma = \frac{1}{T}\int_0^T \sum_{k=1}^{m} u_k i_k dt\,; \quad \left\| u_\Sigma \right\|^2 = \sum_{k=1}^{m} \left\| u_k \right\|^2\,. \tag{3}$$

The above calculation (Fig. 3) provides directly the supply current after compensation when total compensation is expected. Two Butterworth low pass filters of third order and passband edge frequency of

100π rad/s are used to calculate P_Σ and $\|u_\Sigma\|^2$.

Then, the reference compensating currents are the phase non-active currents as defined by FBD theory [5]:

$$i_{kn} = i_k - i_{ka}. \quad (4)$$

b) Generalized instantaneous reactive power theory– based block

According to the generalized instantaneous reactive power (GIRP) theory proposed by Peng, the instantaneous active and non-active current vectors are expressed as [6]:

$$\boldsymbol{i}_p = \frac{p}{\|\boldsymbol{u}\|^2}\boldsymbol{u}; \qquad \boldsymbol{i}_q = \frac{\boldsymbol{q}_L \times \boldsymbol{u}}{\|\boldsymbol{u}\|^2}, \quad (5)$$

where $\boldsymbol{u}$ is the instantaneous voltage space vector and $\boldsymbol{q}_L$ is instantaneous non-active power vector defined as the cross product of voltage and load current currents.

The Matlab/Simulink implementation of this approach for total compensation reasons is shown in Fig. 4.

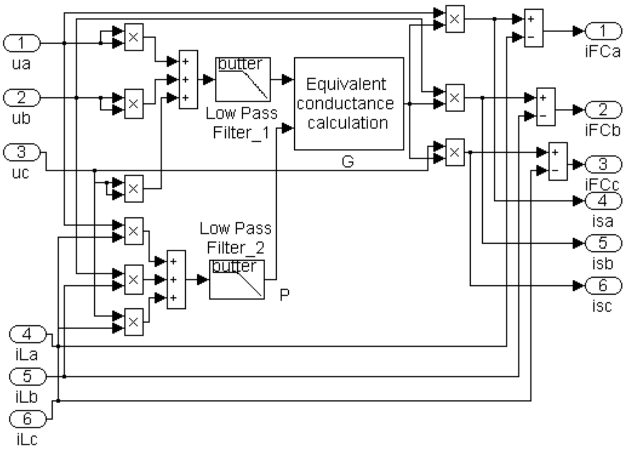

Fig. 3. Structure of the FBD block

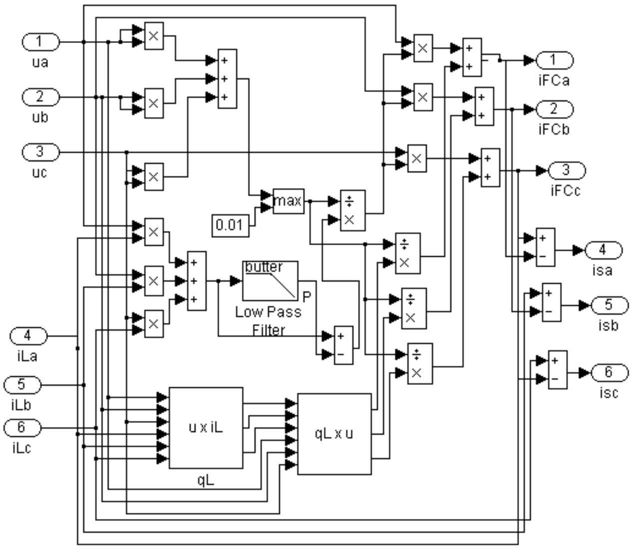

Fig. 4. Structure of the GIRP block

c) Generalized instantaneous non-active power theory– based block

The active (i_p) and non-active (i_q) currents defined through the generalized instantaneous non-active power (GINAP) theory are [7]:

$$i_p(t) = \frac{\frac{1}{T_c}\int_{t-T_c}^{t} p(\tau)d\tau}{\frac{1}{T_c}\int_{t-T_c}^{t} u_p^2(\tau)d\tau}\, u_p(t); \qquad i_q(t) = i(t) - i_p(t), \quad (6)$$

where the reference voltage $u_p(t)$ can be either the supply voltage or its fundamental component.

As shown in Fig. 5, this theory can be easily applied to calculate the desired supply current and then the reference compensating current in the total compensation case.

d) p-q theory– based blocks

Based on the Akagi's so-called p-q theory [4], the following decomposition of the current can be highlighted [8]:

$$\underline{i} = \frac{2}{3}\cdot\frac{P}{|\underline{u}|^2}\underline{u} - \frac{2}{3}\cdot\frac{Q}{|\underline{u}|^2}j\underline{u} + \frac{2}{3}\cdot\frac{p_\sim}{|\underline{u}|^2}\underline{u} - \frac{2}{3}\cdot\frac{q_\sim}{|\underline{u}|^2}j\underline{u}, \quad (7)$$

where: $\underline{u}$ and $\underline{i}$ are the instantaneous voltage and current space vectors; $|\underline{u}|^2$ is the square of the voltage vector modulus; P, Q, $p_\sim$ and $q_\sim$ are the DC and AC components of the real (p) and imaginary (q) parts of the instantaneous complex power.

Note that a transformation from the phase coordinates system to the orthogonal stationary reference frame α-β is needed.

In the block diagram of Fig. 6, the calculation is carried out to provide directly the compensating currents for total compensation. The remaining supply current is calculated too.

A more simplified calculation for total compensation is performed through the p-q_is block (Fig. 7) which generates first the desired supply current after compensation and then the reference compensating current.

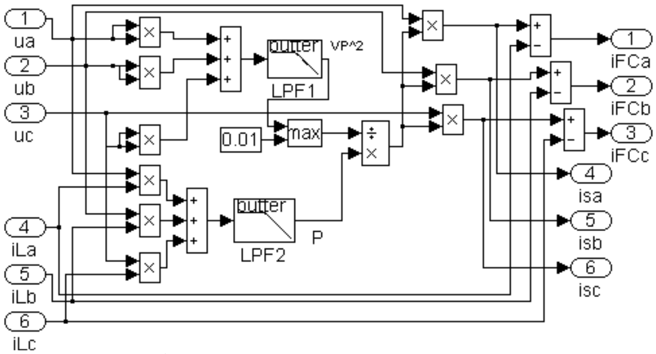

Fig. 5. Structure of the GINAP block

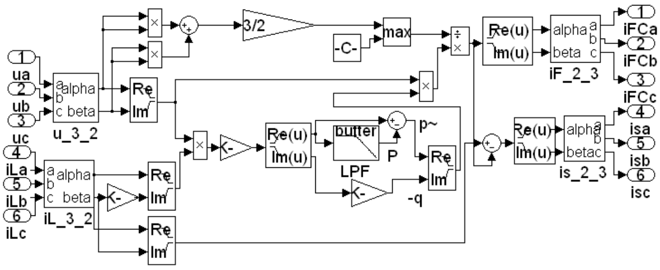

Fig. 6. Structure of the p-q_iF block

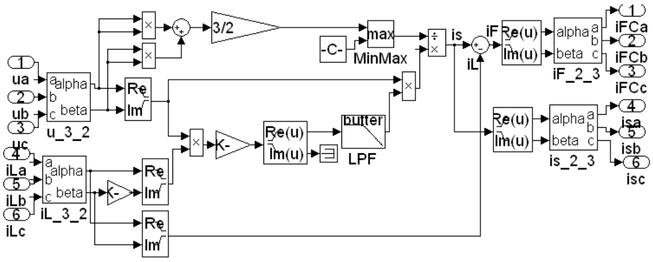

Fig. 7. Structure of the p-q_is block

In the library of Fig. 2, two specific blocks (p-q_iF_partial and p-q_is_partial) are added for the partial compensation case of the current harmonic distortion (without the reactive power).

4. NUMERICAL RESULTS

The waveforms in this section are achieved by using the library blocks for total and partial compensation when the non-linear load consists of an AC voltage controller of high total harmonic distortion factor (about 114%). As expected, the reference current calculation method has influence only on the computing time with implications in practical implementation of the system.

As it can be seen in Fig. 8, an appropriate compensating current is generated in order to compensate both the harmonic distortion and reactive power.

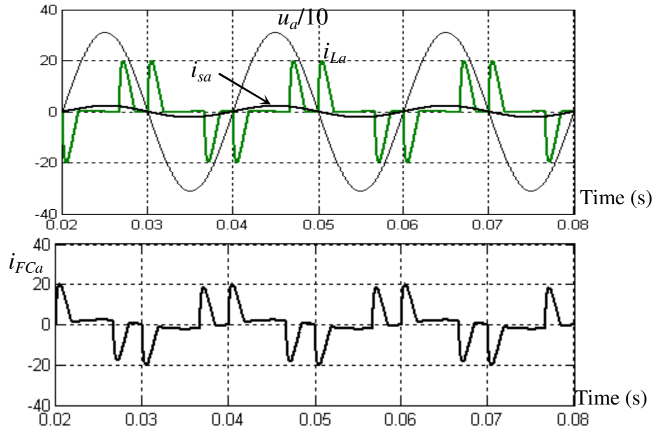

Fig. 8. Input and output waveforms of the reference current generation block for total compensation case through FBD method

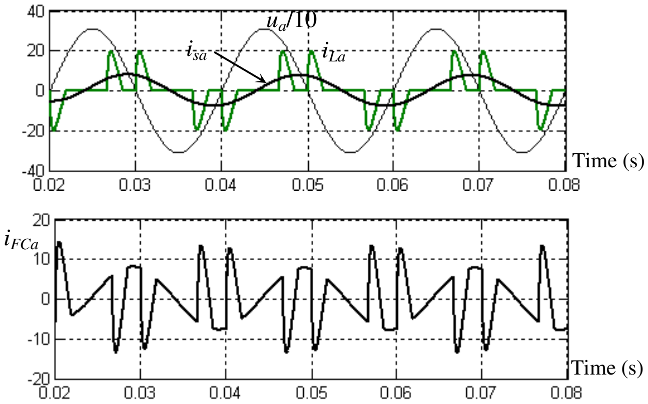

Fig. 9. Input and output waveforms of the reference current generation block for partial compensation case through p-q method

When the compensation strategy requires only the harmonic distortion compensation, the inverter task is diminished and the supply current after compensation will be sinusoidal (Fig. 9).

5. CONCLUSIONS

In this paper, different approaches on the compensating current calculation were implemented in a unified manner and included in a specific Matlab/Simulink library.

The library was implemented on an existing real-time DSP controlled experimental setup which was developed for the study of the three-phase shunt active filtering system. It is based on dSPACE 1103 board working together with Matlab/Simulink software.

After including of each component of the library in the integrated environment for real-time control, additional arguments for choosing the most appropriate algorithm will be available.

Additional blocks corresponding to other theories and strategies can complete this library.

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