Using dSPACE in the
Shunt Static Compensators Control

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Abstract— **This paper presents the design and implementation of an active filtering system based on a DSP acquisition board. This approach has the advantage of versatility regarding the command and control section of the filtering system, for a given power topology. The power section contains the typically components of an active filter, such as the three phase voltage source inverter, the first order interface filter, and the compensating capacitor. Thus, the rated power of the filtering system is imposed by the compensating capacitor value, and by the power transistors rated current and voltage. On the other hand, the command and control section of the filter is limited only by the system transducers. Therefore, the system can have any compensating current computation algorithm, which can also be changed at any moment, and, at the same time, the system can have any topology for the current and voltage regulating loops. Although the active compensator can be controlled using a physical control panel, the easiest and most versatile way is to use a virtual control panel, which can be built using the acquisition board specific software. The disadvantage of this system is that the industrial computer which contains the acquisition board must be located in the close vicinity of the inverter.**

Keywords*: DSP, acquisition board, active filtering*

I. INTRODUCTION

The command and control algorithm of the active filter is based on the dSpace DS1103 acquisition board [1]. This board has all the required interfaces with the active filtering system, such as: analog to digital converters, digital to analog converters, digital I/O ports, PWM modulators, etc [2]. The active filter control algorithm for the DS1103 board consists of a Matlab Simulink model, which uses generic or user defined blocks, and of course, the model input and output blocks, specific for the DS1103 [1][2]. These specific blocks are the software interface between the Simulink signals and the board input and output ports. Consequently, there are blocks in conjunction with the ADCs for the monitored signals acquisition and blocks in conjunction with the DACs and digital I/O ports, which outputs the command signals to the system.

II. THE ACTIVE FILTERING SYSTEM

The active filtering system illustrated in Fig. 1 contains two important sections, besides the power grid and the load [3].
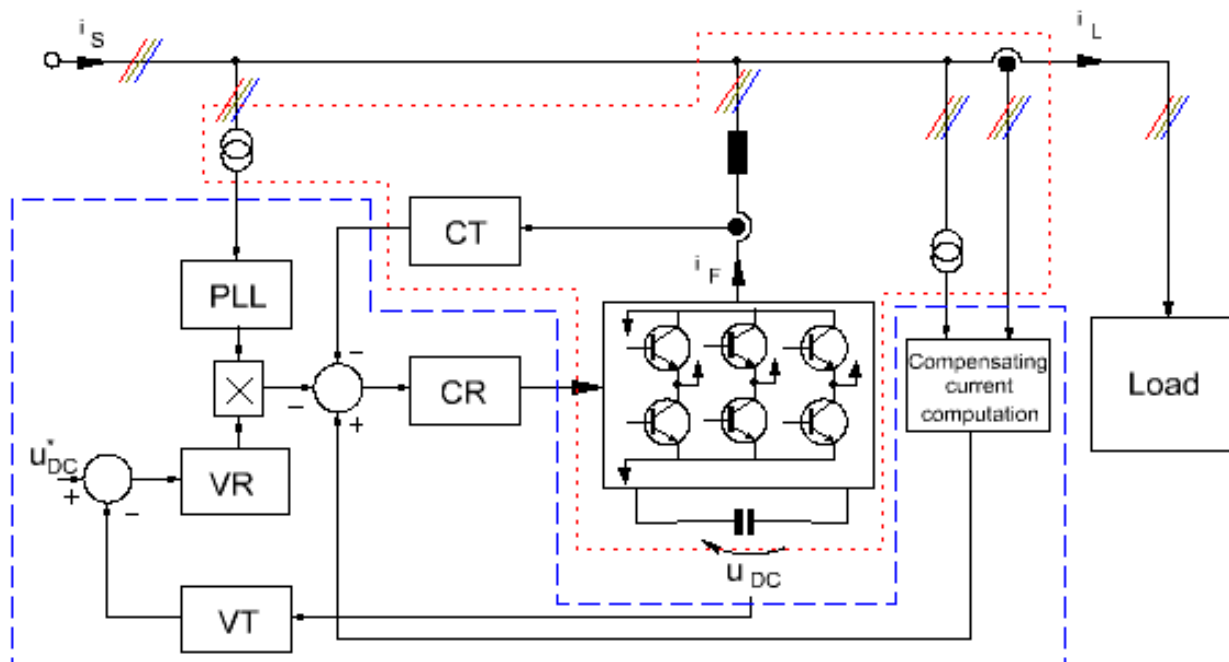

Fig. 1. The active filtration system block diagram

These sections are:

- The hardware section – framed with red dotted line; this section includes all the physical components of the system such as: the power inverter, the interface filter and the compensating capacitor, but also the auxiliary components, such as: the voltage and current transducers, the overload, short-circuit and overvoltage protection circuits, the amplification circuits, and so on [3];

- The software section – framed with blue dashed line; this section includes all the computed components of the system, such as:

  o the compensating current algorithm (in this case, the p-q theory) [4-7];
  o PLL - the phase locked loop necessary for the determination of the grid voltage frequency and phase [3];
  o CT, VT – the current transducer and the voltage transducer as components of the structural diagram;
  o CR, VR – The current regulator and the voltage regulator, which are part of the two regulating loops (one for the filtering current regulation and the other one for the DC-Link voltage regulation).

The rated values of the corresponding physical elements of the active filtering system hardware are:

- The three-phase power inverter IGBTs:
  o V_{CES} = 1200 V;
  o I_C = 100 A;
- The first order interface filter:
  o L = 4.4 mH;
- The compensation capacitor:
  o C = 1100 μF, U_N = 800 V;
- The DSP platform:
  o dSpace DS1103.

The polluting load, used for verifying the system correct implementation was a three phase AC Voltage Converter, especially designed to investigate the shunt active compensators. This nonlinear load is composed of three identical single phase AC voltage converters which can be connected in Δ or Y configuration. The converter load is a passive inductive load, therefore no active power is absorbed.

III. THE ACTIVE FILTER CONTROL ALGORITHM

The Simulink model, which implements the active filter current computation and control algorithm, was built by grouping all the sections in a distinct block (

Fig. 2). The advantage of using such a block is the easy pass from the study by simulation to the experimental study. This way the models corresponding to the power section are removed and the input and output ports of the acquisition platform are connected to the computation block (

Fig. 2) [2]. Because the same Simulink block is used by simulation as well as in the experimental study, the necessary validations for a correct operation (coupling the active filter to the grid, charging the compensating

capacitor and starting the compensation) are established using the constant red inputs of the block. More than that, the cyan inputs of the block are used to select the compensating current computation method (referring to the partial or total compensation) and the grid voltage shape considered in the compensating current computation. These setup inputs are necessary because in the experimental study, all the validations are available on the active filter virtual front panel.

The internal structure of the active filter control block is illustrated in **Fig. 3** and is based on the active filters specific schematic diagram (Fig. 1), containing the two regulating loops: the compensating current regulation, and the DC-Link voltage regulation loop [3][8-11]. The same modular structure was kept in the model, in order to have a clear view of the system, but especially for making the model easy to be debugged and improved.

Because the active filter includes only two transducers (instead of three) for each measured current or voltage system, three specific blocks were used in order to obtain the complete three phase systems (for the compensating current, load current, and grid voltage system, respectively).

This is because the power inverter has a three-wire configuration, the not measured current being mathematically determined using the first Kirchhoff theory. In case of the grid voltage, the three phase voltages were computed using two line voltages (u_{ab}, u_{ac}). Also, because of the transducers mounting strategy, the currents absorbed from the grid are measured with opposite sign to the real, therefore, the sign conversion blocks are necessary. The yellow Gain blocks are used for the sign conversion, but also for the signal conditioning (this is necessary because the transducers output signals are enclosed in the ±1 V domain). Thus, starting from the rated values of the transducers, the proportionality constants of the current and voltage transducers are the following:
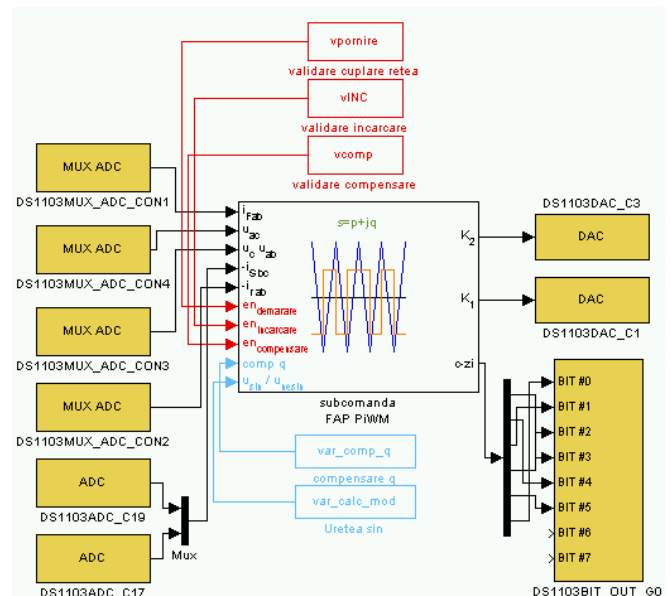
$$G_{TI} = -100, \quad G_{TU} = 1500$$

Fig. 2. The Simulink model of the active filter control algorithm
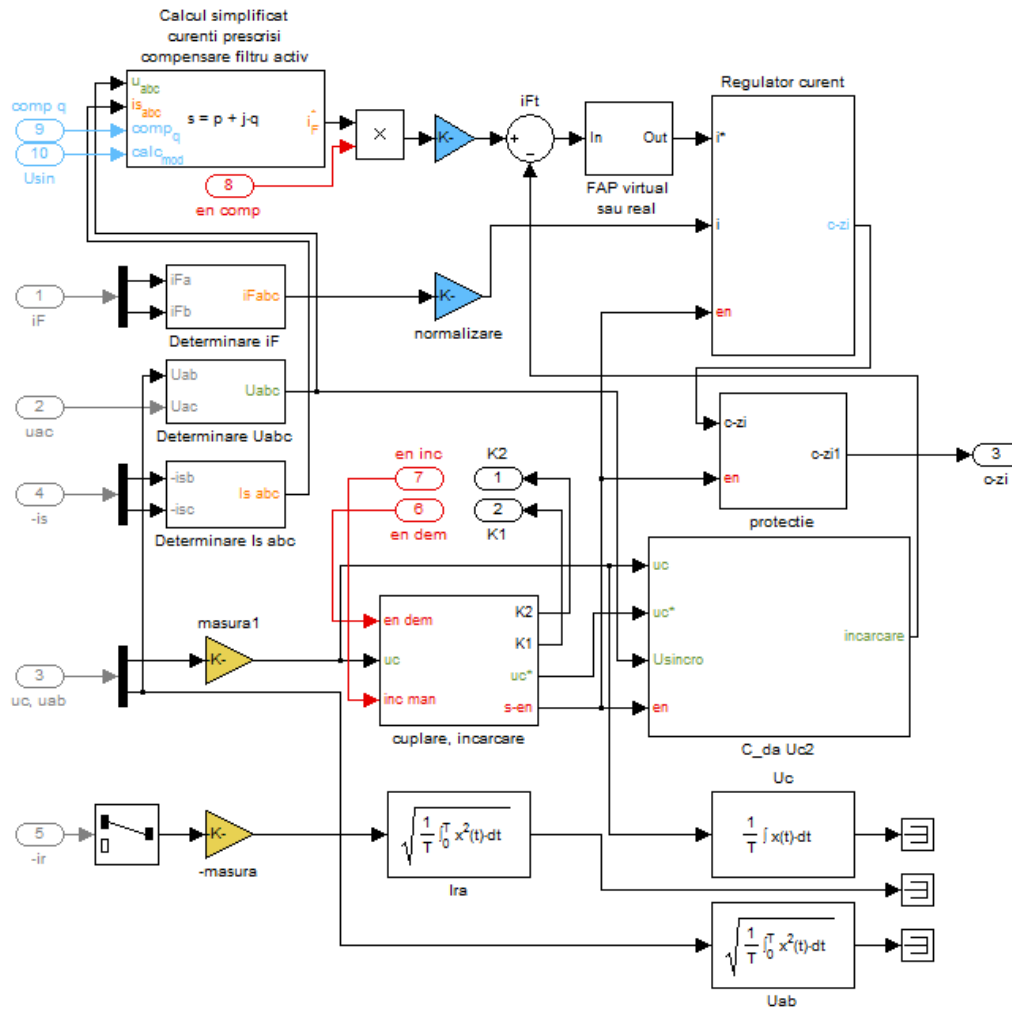
Fig. 3. The internal structure of the active filter computation and control block

Especially when using regulators, in order to operate in the standard domain (0 ÷ 10 V), some normalization blocks were used (the cyan *Gain* blocks).Taking into account the rated values of the active filter, i.e. a current of 25 A and a compensating capacitor maximum voltage of 800 V, the normalization constants are:

$$G_{ni} = \frac{10}{25} = 0.4 , \; G_{nu} = \frac{10}{800} = 0.0125$$

The two regulating loops are located in two corresponding blocks. Thus, the DC-Link voltage regulation loop is located in the *C-da Uc2* block (Fig. 4).
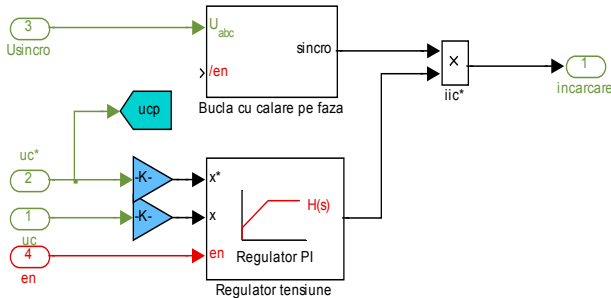
This block is not only used to generate the reference currents necessary for the DC-Link voltage regulation, but also for the compensating capacitor charging (from 560 V to the imposed value – typically 700 V). This is because the charging is done by absorbing from the power grid an imposed active current (sinusoidal and in phase with the grid voltage) whose amplitude is equal to the voltage regulator output value [3].

The imposed currents to be absorbed from the grid are obtained by multiplying the voltage controller output with a three-phase current system of unitary amplitude with the same phase as the grid voltage, obtained at the output of a phase locked loop (Fig. 4).

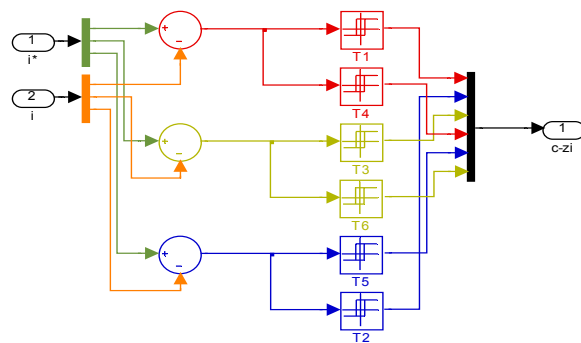Fig. 4. The DC-Link voltage regulation and capacitor charging block

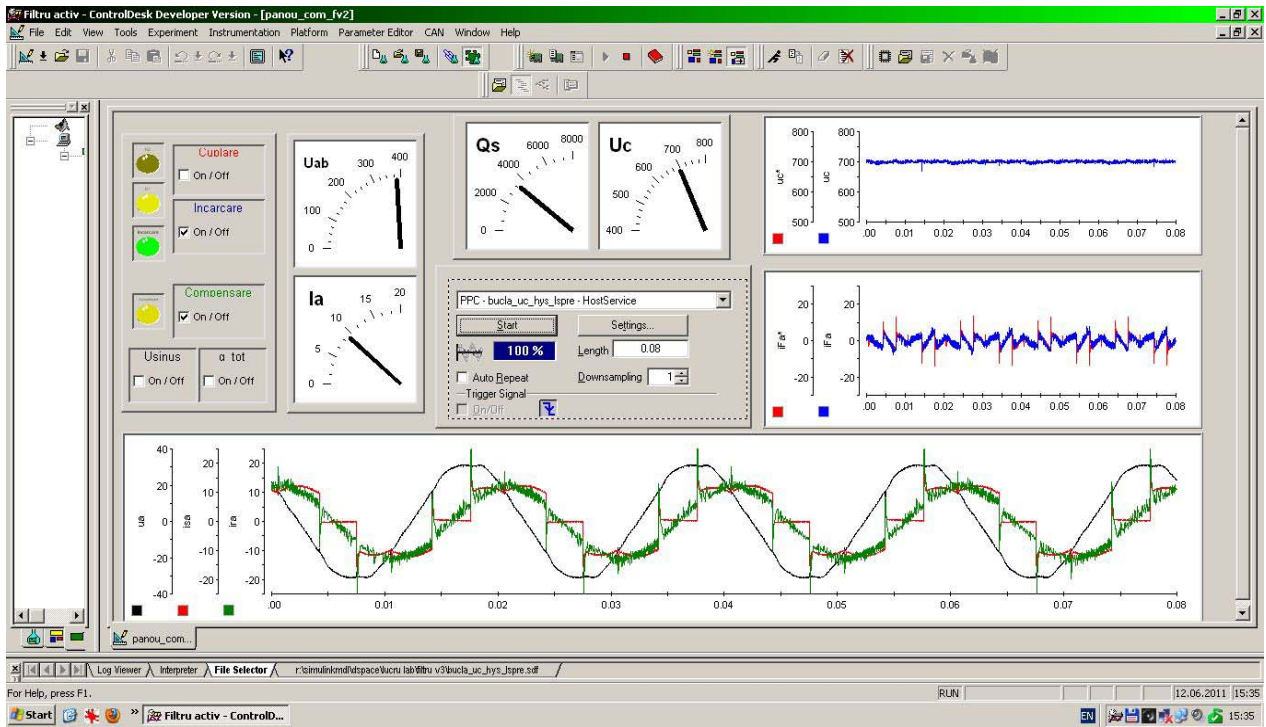Fig. 5. The hysteresis current regulation loop

Fig. 6 The active filter virtual control panel

The second regulating loop is located in the *Regulator current* block (Fig. 5). Despite the voltage regulator which is a proportional-integrative regulator, the current regulator is a simple and robust hysteresis regulator. This regulator has the advantage of simplicity, as seen in the figure. More than that, no tuning is required. On the other hand, this solution has the disadvantage of the variable switching frequency. Because the hysteresis band is kept constant, the switching frequency is dependent on the filter current slope [3].

The binary program for the DS1103 DSP is obtained by compiling the Simulink model in Fig. 2, used to implement the active filter control algorithm, which means the model is converted to a C program which is also converted to a binary program uploaded to the DSP memory.

The active filter user interface is based on the DS1103 specific software (Control Desk), and consists of the virtual control panel illustrated in Fig 6. The front panel contains all the necessary virtual instruments, such as check buttons, indicator lamps, etc, and also, the system monitoring devices (virtual panel meters, oscilloscopes, etc). It must be mentioned that the panel meters are only displaying the quantity (e.g. a mean or RMS value) the calculation is done by the corresponding Simulink block.

The link between the control panel instruments and the corresponding variables of the Simulink model are also made by the Control Desk software. These links are automatically loaded to the DS1103 memory at the program compilation.

Fig. 7. The experimental active filter
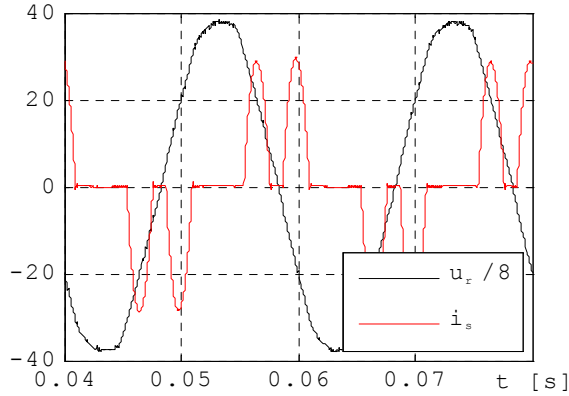

Fig. 8. The experimental nonlinear load

IV. EXPERIMENTAL RESULTS

As stated, the presented control algorithm was experimentally tested using a three phase shunt active compensator which contains only the power and interface / protection circuits (Fig. 7). The control of the active compensator was achieved only through the DS1103 control algorithm. All the raw data (grid voltages and currents, load currents, etc) measured by the system transducers was transferred to the DSP board, which generated the gating signals applied to the filter power transistors (via the corresponding circuitry). Also, for the conducted experiments, the nonlinear load was a three-phase AC voltage converter, specially designed for the active compensators testing (Fig. 8). This converter absorbs from the power grid a current similar to the current absorbed by the drive systems with PWM inverters and induction motors (Fig. 9). The difference is that the current in Fig. 9 contains no active component.
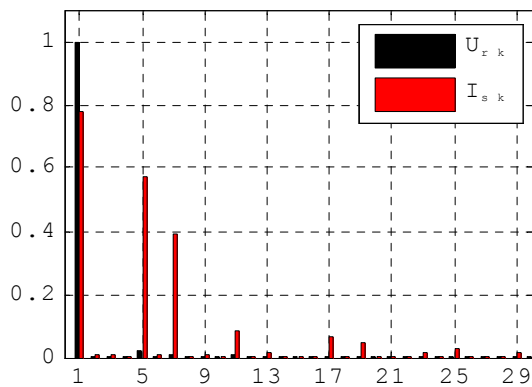
The total harmonic distortion factor of the load current is 90.64%, for a grid voltage THD of 2.75%. It can be observed in Fig. 9-b the presence of the 3rd harmonic, because the load currents RMS values are established independently for each phase. Consequently, the load current system cannot be perfectly balanced.

It must be mentioned that the total harmonic distortion factor was calculated considering the current fundamental RMS value at the denominator:

$$THD = \frac{\sqrt{\sum_{k=1}^{\infty} I^2_k}}{I_1} = \sqrt{\left(\frac{I}{I_1}\right)^2 - 1} \qquad (1)$$

Also, the current harmonics RMS values in the harmonic spectra are relative to the current fundamental RMS value.

The compensated current waveform and harmonic spectra are illustrated in Fig. 10. The adopted compensation strategy was the partial compensation (for the p-q theory this means that only the fluctuating parts of p and q are to be compensated, the reactive power, i.e. the average value of q, is not compensated).
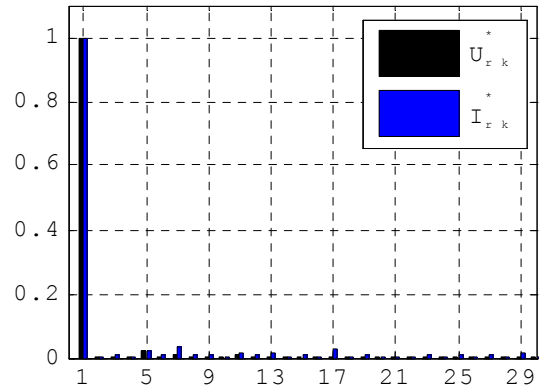
After the compensation, the current total harmonic distortion was reduced to 11.05%, giving a filtration efficiency of 8.20. The current distortion can be even more reduced, by reducing the current regulators hysteresis band, which in this case is about 2 A. Also, for the same hysteresis band, the current distortion lowers when the current fundamental increases.

The ratios of the RMS values before and after the simulation of the significant harmonics are graphically illustrated in Fig. 11. It results that for the filtration efficiency of 8.2, the harmonics are efficiently reduced, the 5th harmonic being reduced up to 30 times, the 7th up to 15 times, and so on. Another interesting fact is that the fundamental harmonic ratio is practically inexistent. This is because the nonlinear load is inductive and has no active current; the very low active current being absorbed is due to the converter losses.

Considering the total compensation algorithm (for the p-q theory, this means that all the non-active components of the load current are to be compensated, i.e. the fluctuating component of p and the entire imaginary component, q), the grid current global RMS value is reduced from about 15 A to 1.6 A.

(a)

(b)

Fig. 9. The nonlinear load current waveform and harmonic spectra
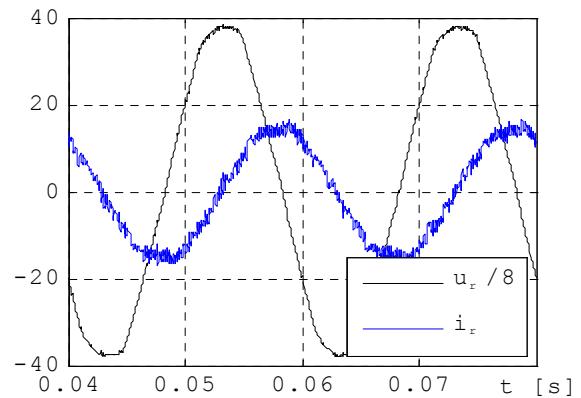
(a)

(b)

Fig. 10. The compensated current waveform and harmonic spectra for the partial compensation
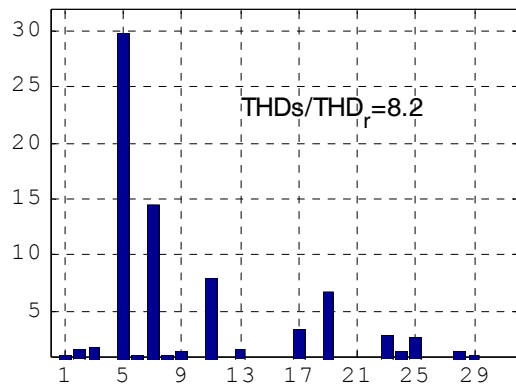
Fig. 11. The ratios of the significant harmonics before and after the simulation

This means that in the case of total compensation, the active compensator is supplying the nonlinear load with both harmonic and reactive current, which, in fact is the entire load current. Therefore, the current which remains to be absorbed by the load from the power grid is only the current necessary to cover the converter losses.

Because the load current has no fundamental component, so the remaining current after the compensation is practically null, the current THD has no meaning in this case.

CONCLUSIONS

The design and implementation of an active compensator regarding the command and control section can be accomplished based on a DSP acquisition board. This approach is having the advantage of versatility, for a given power topology because the control algorithm can be easily changed and improved. Also, the compensating current computation method can be easily changed. At the same time, the system performance can be analyzed using the DSP board acquisition and computation facilities. Another advantage of this approach, is the virtual instrumentation available through the board specific software, which eliminates the need for a physical control panel.

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