Active Power Filter Study Using Dedicated Matlab GUI

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***Abstract -*This paper presents an understandable and friendly Matlab interface, which shows the active filtering role in a simple manner for the users. The created interface allows the active filtering system simulation, choosing the compensation mode. All these are necessary to plot the available workspace variables and to assess the active filtering performance. Moreover it displays the total harmonic distortion values, for the load and grid current, and computes the filtering efficiency The Simulink model was created for a three-phase non-sinusoidal voltage system, the current components being computed using the Conservative Power Theory elaborated by Paolo Tenti. The analyzed system contains a three-phase full wave controlled rectifier with a passive RL load. After the model simulation, the interface will illustrate the grid current and voltage waveforms, before and after the compensation, for both partial and total compensation. The mentioned graphics, as well as the waveform of the reactive current component, will make the user understand the Active Power Filter (APF) functions, i.e. improving the shape of the current absorbed from the power grid and improving the power factor. The created interface can be used as an educational tool in finding that APF is a solution to fix the disturbing effects that non-linear loads, supplied by the power grids, produce to them.**

Keywords: *graphical user interface, simulation, active power filter, conservative power theory, partial and total compensation.*

I. INTRODUCTION

The active power filtering is a well-known efficient solution and powerful tool for power quality improvement, mainly due to its versatility and capability to achieve different compensation goals.

The objective of the active filter is to determine and generate the necessary harmonic current to be fed to the non-linear loads. If the harmonic current is supplied by the active filter, the non-linear loads will absorb from the power grid only the active current (and the reactive current in some cases).

A complete energetic analysis must refer to the total harmonic factor distortion (THD) at the point of common coupling (PCC), as well as the powers transferred between the grid and the load. Consequently, active filters design and control was an important research topic for the recent years.

Most of the computation strategies are based on the current compensation techniques, for example the non-active current compensation, and on the instantaneous power compensation.

There are many theories for the reference compensating current computation, based on either time-domain or frequency domain. In this study, the used current computation method was the Conservative Power Theory. For an easy understanding, it was created a Matlab interface which emphasizes the active power filter principle.

A user interface (UI) is a graphical window which contains controls, allowing the user to perform interactive tasks. The user does not have to create a script (m-file) or enter commands at the command window to accomplish the desired work. Thus, the user does not need to understand the details of how the tasks are performed [1] – [4].

In order to work with GUI (Graphical User Interface), the graphical system MATLAB ("Handle Graphics") contains the graphical objects category, named UIObjects, and gives the necessary support GUIDE ("GUI Development Environment").
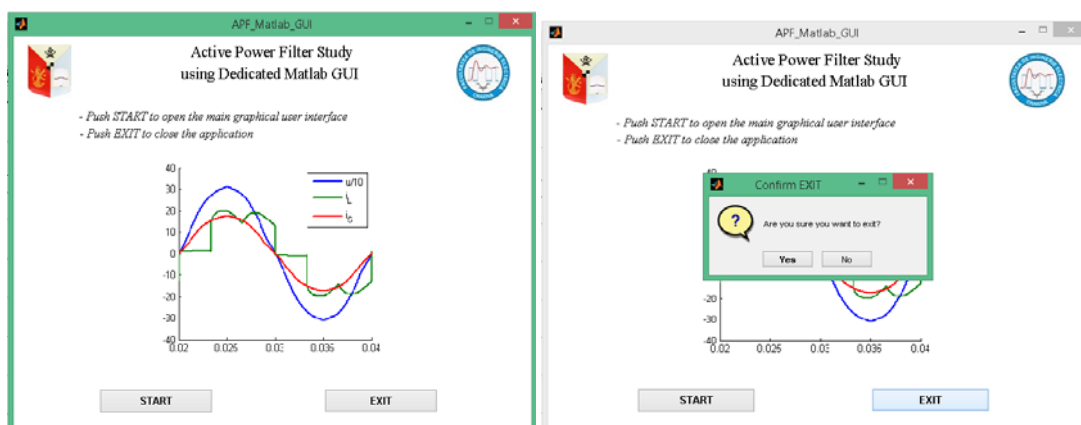

Fig. 1. The initiation user interface.

The development of a GUI can also be done using coded instructions, but mostly GUIs are created with GUIDE, subsequently adding programming items. UIs created using MATLAB tools can perform any type of computation, read and write data files, communicate with other UIs, and display data as tables or as graphics [5] – [9].

When a UI is created using GUIDE, a blank figure is automatically opened, so it can be populated with components available in a component palette. GUIDE creates an associated code file containing callbacks which correspond to the UI and to the inserted components. GUIDE saves both the figure and the code file, the application being launched from either file.

The paper introduces an intelligible and friendly Matlab GUI which illustrates the active filtering role in a simple manner for the user but complex through the available facilities. The APF_GUI can be used as an educational tool in finding the objective of the active filter. Its role is to determine and generate the necessary harmonic current to be fed to the non-linear loads.

II. Main Components Of The Created Interface

The interface, that it would be depicted further, was created using GUIDE, and then code programming was added.

First, it was created an initiation UI containing the following components: static-texts, axes objects with the corresponding images and two push-buttons. The last two buttons have the role to start another interface (the main interface) and, respectively to exit the application (Fig. 1). If the user chooses to push the exit button, a dialog box appears in order to confirm the exit. For this, it was necessary to add some code programming in the created m-file of the interface.

If the user pushes the "START" button, the main Graphical User Interface will be open. The APF_GUI (Active Power Filter GUI), as it will be called from now on, helps the user to understand the APF role, i.e. improving the shape of the current absorbed from the power grid and improving the power factor.

Non-linear loads supplied by the power grids produce disturbing effects to them. So APF is a solution to fix this problem.

The APF_GUI can be used as an educational tool for beginners in the active filtering domain. This interface allows the user to simulate an active filtering system, choose the desired compensation type, display some performance indicators and to select variables (saved in the workspace after the models simulation) in order to plot them. Further, each component of the created interface will be described (Fig. 2). Most common control elements (UIControls) for GUI are push-buttons, radio-buttons, list-boxes, sliders and also can include menus (UIMenus), toolbars and so on.

The created GUI includes the following components:
- a list-box that makes possible the selection of the existing workspace variables;
- two radio-buttons for choosing the desired compensation mode;
- a button-group which holds the two radio-buttons;
- Two static-texts and two text-boxes for the current THD (Total Harmonic Distortion- load current and source current) value.

In order to obtain the THD value the following relation was used:

$$THD = \sqrt{\sum_{k=2}^{n} C_k^2} \Big/ C_1 \qquad (1)$$

- Two boxes for the current THD (Total Harmonic Distortion- load current and source current) value;
- two panels, the first one holding the existing workspace variables and the second holding the performance indicators;
- one push-button placed on the performance indicators panel that computes the filtering efficiency using the equation:
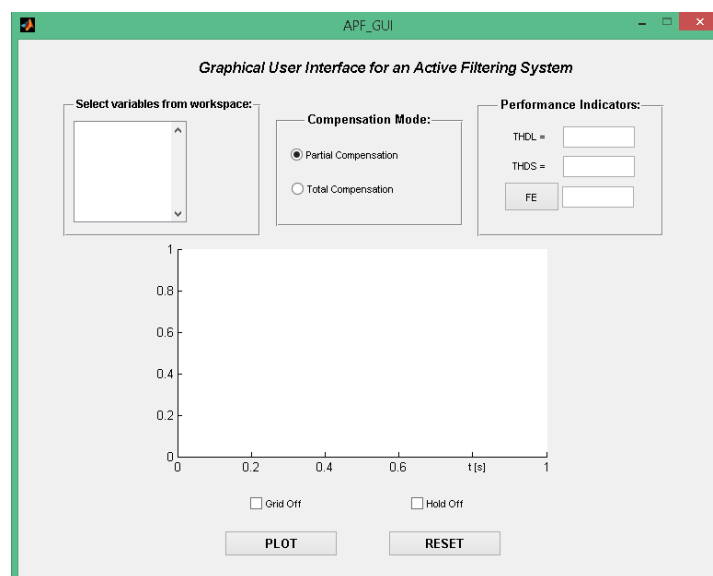
$$FE = THD_L / THD_S \qquad (2)$$
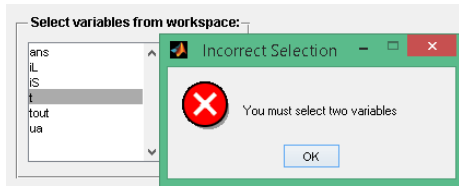

Fig. 2. The main Graphical User Interface.

Fig. 3. Error dialog box.

The obtained result of the equation (2) will be displayed in the boxes near the "FE" push-button.

- one axes object in order to see the waveforms corresponding to the selected workspace variables;
- two push-buttons, one necessary to plot the selected workspace variables and the other used to reset the axes;
- two check-boxes, first displays the major grid lines for the current axes and the second one retains current plot when adding new plot.

It must be mentioned that the two radio-buttons are mutually exclusive, that means the selection of the partial compensation excludes the selection of the total compensation mode. Therefore, if the selected button is "radiobutton1" then, the partial compensation Simulink model will be running, this way being saved the data corresponding to the partial compensation mode. Otherwise, the variables from the workspace will correspond to the total compensation mode. Speaking about workspace variables, the listbox which displays them is programmed so that it will return an error if only one variables is selected and then plotted.

The error dialog box is illustrated in Fig. 3. The Simulink model behind the APF_GUI will be depicted in the following section.

III.   THE SIMULINK MODEL DESCRIPTION

The Simulink model, which is automatically opened as a result of the interface m-file running, is illustrated in Fig. 4. The model was created for a three-phase non-sinusoidal voltage system, in which the current had been calculated with the Conservative Power Theory (CPT) definitions. The system contains a symmetrical non-linear load (a three-phase full wave controlled rectifier with a passive RL load) [1]. The current terms (Fig. 5) are defined collectively, by making reference to an equivalent balanced load absorbing the same active power and reactive energy of the analyzed load.

Each current component is defined as follows [10] - [13]:

1a) Balanced active current:

$$i_a^b = \frac{P}{U^2} \underline{u} = G^b \underline{u} \text{ , where:} \qquad (3)$$

- **P** is the three-phase active power of the load:

$$P = P_R + P_S + P_T ; \qquad (4)$$

- **U** is the RMS grid voltage defined as follows:

$$U = \sqrt{U_R^2 + U_S^2 + U_T^2} ; \qquad (5)$$

- G^b is the equivalent balanced conductance.

1b) Unbalanced active current:

$$i_a^u = \underline{i}_a - \underline{i}_a^b \Rightarrow \underline{i}_{an}^u = \left(G_n - G^b\right)u_n, n = 1 \div N \qquad (6)$$

2a) Balanced reactive current:

$$i_r^b = \frac{\langle \hat{u}, \hat{i} \rangle}{\|\hat{u}\|^2} \hat{u} = \frac{W}{\hat{U}^2} \hat{u} = B^b \underline{u} \qquad (7)$$
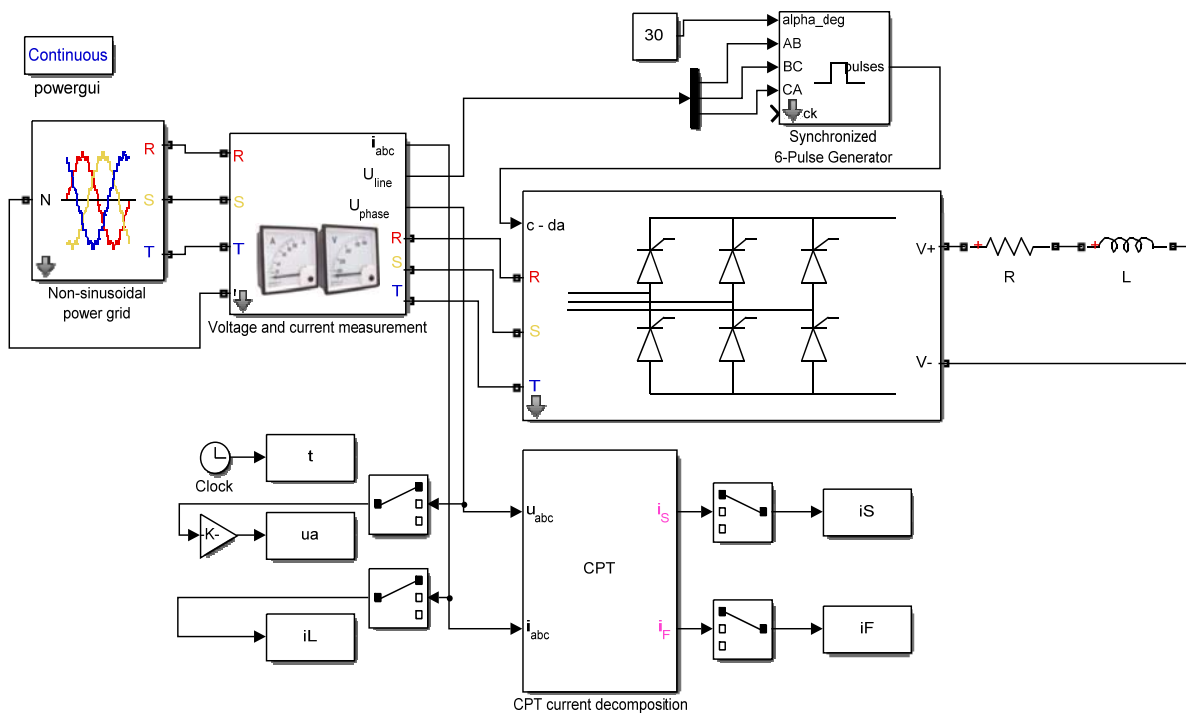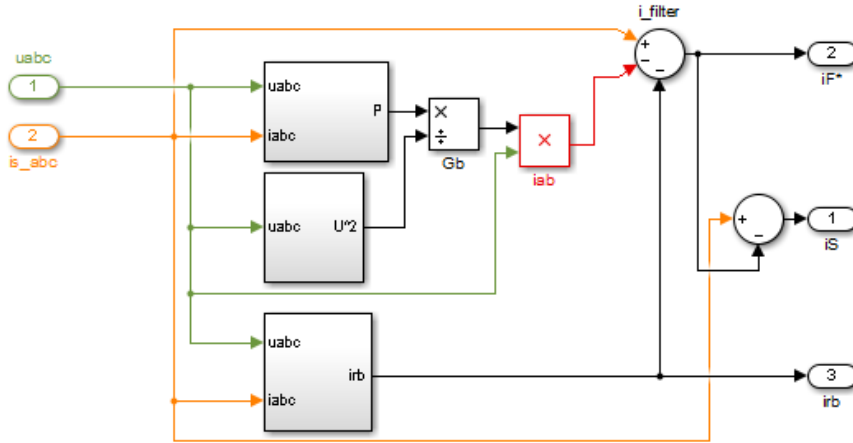

Fig. 4. The Simulink model.

Fig. 5. The CPT current components block.

- $\langle \hat{u}, i \rangle = \dfrac{1}{T} \displaystyle\int_0^T \hat{u} \cdot i\, dt$ is the internal product;

- $\hat{u} = \omega \cdot \left(\displaystyle\int_0^t u(\tau)\, d\tau - \dfrac{1}{T} \int_0^T \int_0^t u(\tau)\, d\tau\, dt \right)$ is the time integral;

- W is the three-phase reactive energy absorbed by the load and B^b is the equivalent balanced susceptance.

2b) Unbalanced reactive current:

$$\underline{i}_r^u = \underline{i}_r - \underline{i}_r^b \Rightarrow \underline{i}_{rn}^u = \left(B_n - B^b \right) \hat{u}_n, \, n = 1 \div N \quad (8)$$

The compensating current will be computed from the load current depending on the compensation goals:

- total compensation – the active filter will compensate the entire non-active current:

$$\underline{i}_F^* = \underline{i}_L - \underline{i}_a \quad (9)$$

- partial compensation – the active filter will compensate only the distorted component:

$$\underline{i}_F^* = \underline{i}_L - \underline{i}_a - \underline{i}_r \quad (10)$$

The simulation results will be displayed using the APF_GUI, the waveforms being obtained by plotting the workspace variables resulted after the simulation. The following section illustrates them for both partial and total compensation cases.

In order to obtain the GUI waveforms illustrated in Fig. 6 - Fig. 8, the user has first to choose the compensation mode, then select the desired variables to plot them.
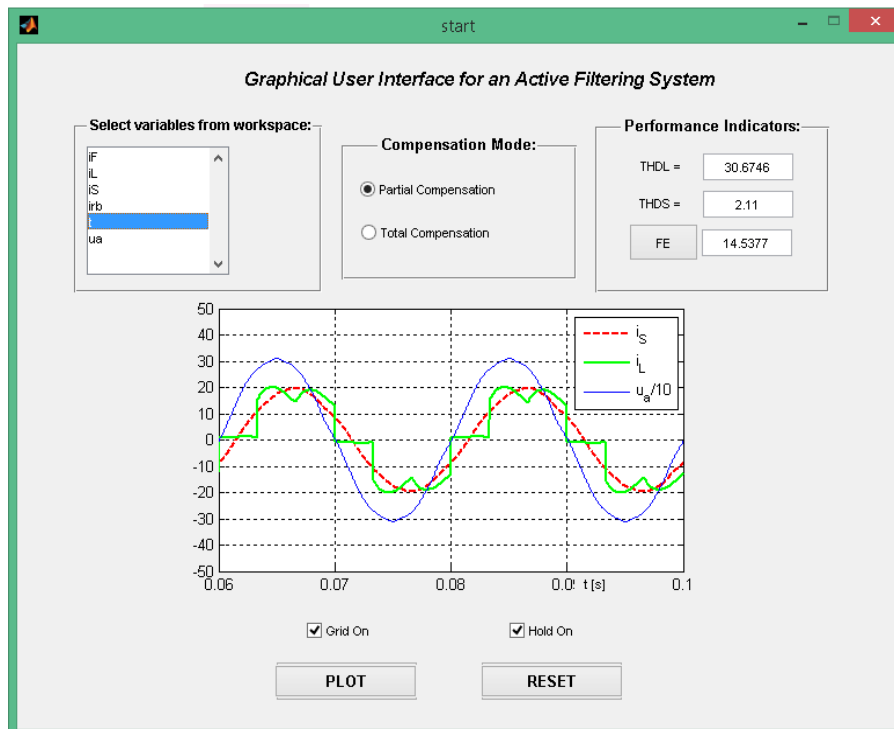

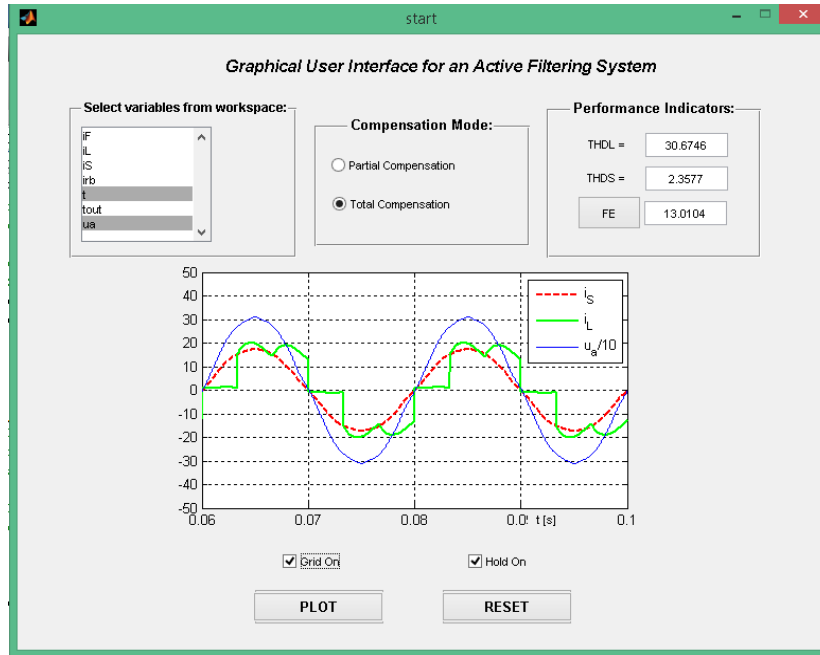Fig. 6. APF_GUI waveforms for partial compensation mode.

Fig. 7. APF_GUI waveforms for total compensation mode.

The values of the performance indicators are displayed as soon as the user clicks the corresponding boxes. The waveforms and the performance indicators, for the partial compensation case, are illustrated in Figure 6.

Thus, some conclusions can be drawn by the user, i.e in case of partial compensation only the distorted component of the current has been compensated, so the grid current keeps its reactive phase shift to the grid voltage. This is because the compensating current was computed using the relation (10). However, the harmonic distortion of the compensated current decreases from 30.67 % to 2.11 %, giving a filtration efficiency of 14.53. This explains the almost sinusoidal shape of the grid current. The waveforms and the performance indicators, for the total compensation mode, are illustrated in Fig. 7. It can be noticed that the grid current and the grid voltage have similar shapes, the phase shift between them being eliminated. It must be mentioned that the compensated current was computed using relation (9). The eliminated current components were the reactive and the distorted components.
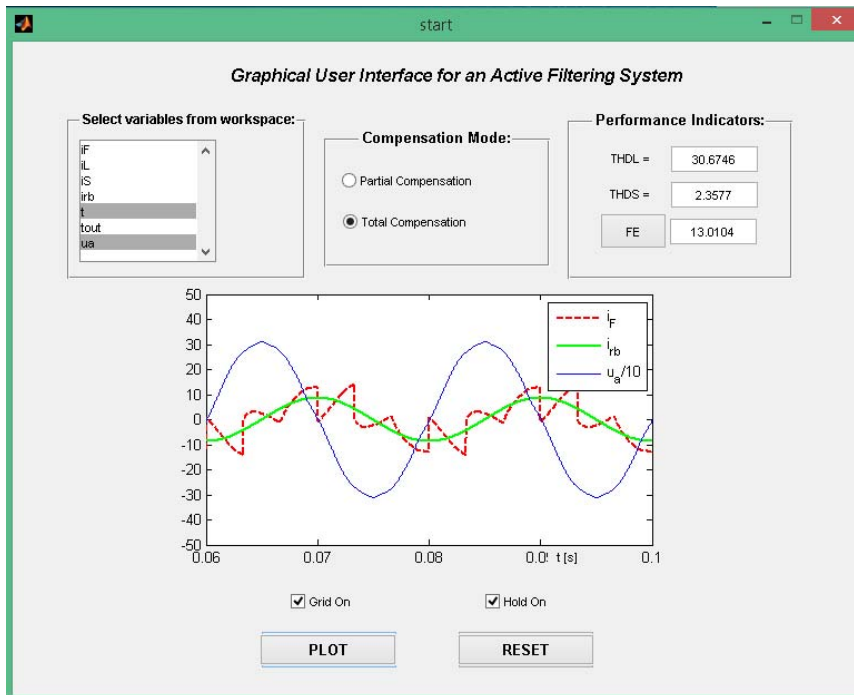

Fig. 8. The reactive and compensating current waveforms.

Regarding the compensated current harmonic distortion, the current THD had been reduced from 30.67% to 2.35%, giving a filtration efficiency of 13.01.

It must be mentioned that the reactive and compensating current waveforms (Fig. 8) were obtained using the relations (7) and (9), the phase shift between the grid voltage and the reactive current being visible. Analyzing the active filtering system, it was shown that the CPT method, by its current components, allowed both partial and total compensation, being an advantage when the reactive power compensation is not necessary.

IV.   CONCLUSIONS

In this paper, APF_GUI tool (Active Power Filter Graphical User Interface) was introduced. This interface shows the active filtering role in a simple manner, allowing the user to simulate an active filtering system, choose the desired compensation type, and to select the variables to be plotted. Moreover it displays the total harmonic distortion values (for the load and grid current) and computes the filtering efficiency.

The APF_GUI can be used as an educational tool in finding the objective of the active filter. Its role is to determine and generate the necessary harmonic current to be fed to the non-linear loads. If the harmonic current is supplied by the active filter, the non-linear loads will absorb from the power grid only the active current.

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