Proceedings of the Seventh IASTED International Conference
POWER AND ENERGY SYSTEMS
August 29–31, 2007, Palma de Mallorca, Spain
ISBN Hardcopy: 978-0-88986-689-8 / CD: 978-0-88986-690-4

POWER QUALITY ASSESSMENT VIA MATLAB/SIMULINK –BASED TOOL

Mihaela Popescu, A. Bitoleanu, M. Dobriceanu, M. Linca
Faculty of Electromechanical Engineering, University of Craiova
Craiova, 107, Decebal Street, 200440
Romania
{mpopescu, abitoleanu, mdobriceanu, mlinca}@em.ucv.ro

ABSTRACT
This paper introduces the facilities of a new graphical user interface named SEATED for power quality assessment in induction motor and static converter driving systems. It is based on a Matlab/Simulink library created to this end and allows an easy structure and parameters setup. Power quantities and power quality indices are evaluated from the instantaneous values of the voltage and current signals after the system operation simulation up to all imposed steady state operation points. The steady state analysis can be carried out for each steady state operation point both at the network side and at the motor side. For the quantities for which there are more computing possibilities according to the actual powers teories under non sinusoidal conditions, several definitions were taken into consideration such as Budeanu definitions, Czarnecki definitions and phasorial theory. In the display window, the appropriate option can be selected from a popup menu. As an example, a case study of the electrical drive with induction motor and harmonics cancellation inverter fed by a three-phase rectifier is presented. The simulations followed by power quality assessment can be used as educational tools in order to find both the system parameters influences and control strategies influences on the power quality performances.

KEY WORDS
Power quality, simulation, electrical drive, and static converter

1. Introduction

Like any other nonlinear load, variable-speed drives (VSDs) are a source of harmonics in the electrical system. Both current and voltage harmonics can cause potential problems [1]. Running computer simulations provides an ideal method of analysing power quality [2], [3], [4].
A new user-friendly tool called Simulation and Energetic Analysis Tool for Electrical Drive (SEATED), based on MATLAB/SIMULINK package, has been developed for that purpose. Its realization is based on a library created to this end. The electrical driving system with induction motor fed by a voltage source static converter was considered.
The system structure and parameters, simulation, analysis and displaying capabilities are carried out via pull-down menus, push buttons, radio buttons, popup menus, context-sensitive menus, check and dialogue boxes, etc [4].
The attention in the paper is mainly drawn to the description of the most important graphical tool capabilities for power quality assessment.

2. SEATED – main features

When the SEATED tool is invoked, a start-up window appears and allows the user information on the main facilities of this tool as shown in Figure 1.

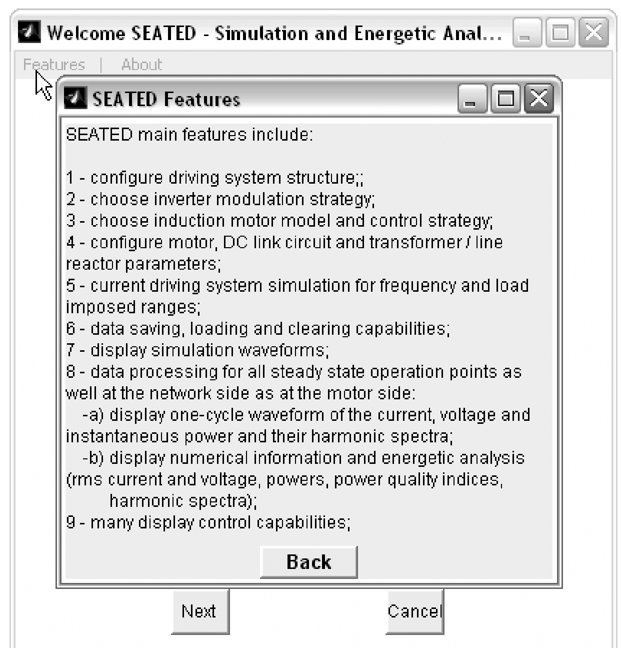

Fig. 1 The start-up window

The main window has seven pull-down menus whose names give information on the actions carried out (Fig.2). The graphical interface allows users to configure the structure of the driving system through many options.

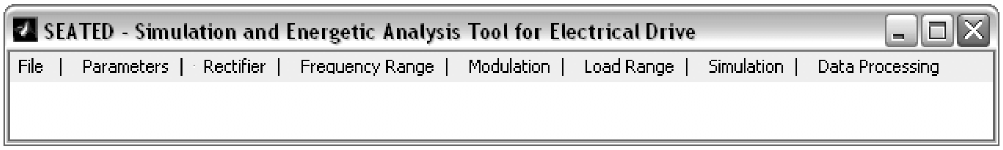

Fig.2 The main window of SEATED

A dialogue window associated with the Parameters menu is used to configure the parameters of the motor, DC link circuit and transformer/line reactor (Fig.3). The user is also able to toggle between selection modes. Thus, the supply voltage of the rectifier can be provided by a transformer or by a line reactor. Moreover, in the induction motor model it is possible to choose the dynamic or the static consideration of the main flux saturation [5], [6]. The neglecting of the saturation effect is possible too.

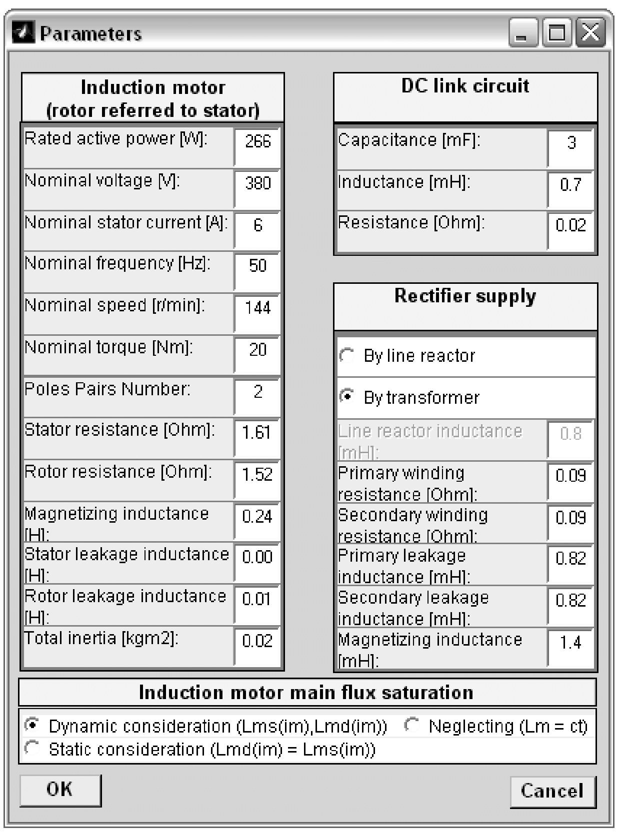

Fig.3 The dialogue window associated with the Parameters menu

The rectifier type can be selected from the Rectifier menu, e.g. single-phase or three-phase scheme (Fig.4).

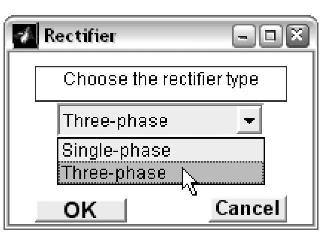

Fig.4 Choosing the rectifier type

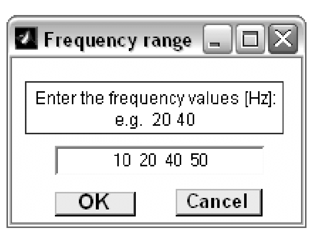

Fig.5 Specifying the frequency range

The steady-state operation points to be analysed are imposed through the similar specific dialogue windows (Fig.5 and Fig.6) associated to the Frequency range and Load Range pull-down menus. The induction motor load torque can be selected to be either active or passive by a pop-up menu in the Load Range dialog window (Fig.6).

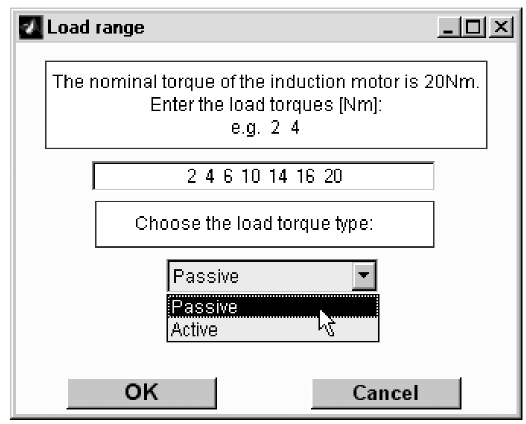

Fig.6 Specifying the load torque range

Using the Modulation menu, the simulation of the system can be carried out using different modulation methods such as sinusoidal (SM), pulse trains (PT) and harmonic cancellation (HC). An adequate dialogue box allows the user to define the modulation parameters and induction motor strategy (Fig.7). A pop-up menu allows choosing among the following modes: the classical constant volts per hertz (*U*/*f*), the constant stator flux, the constant rotor flux and the constant magnetizing flux.

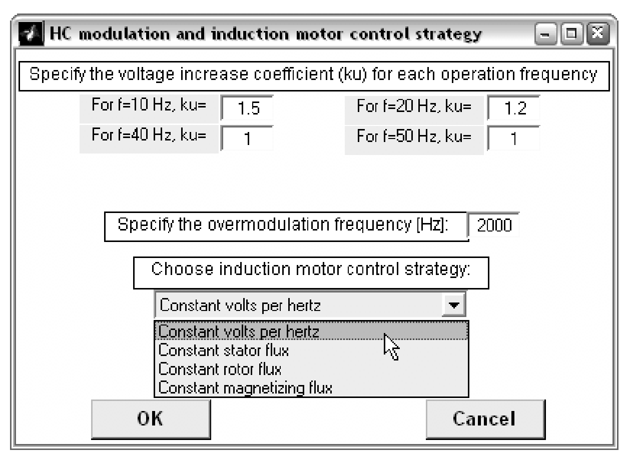

Fig.7 Configure HC modulation and choose control strategy of the motor

The Simulation menu enables the simulation of the electrical driving system till all the steady state operation points are obtained. The user is also able to choose the maximum order of the considered harmonic in the power quality analysis (Fig.8).

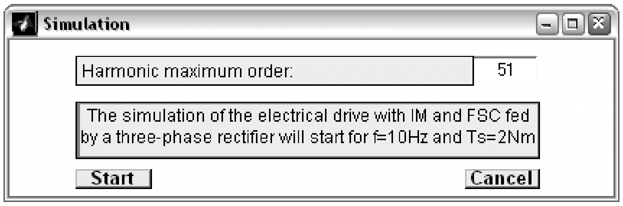

Fig.8 Starting the simulation

The simulation data can be processed and the results can be displayed and represented in graphic form by the Data Processing pull-down menu (Fig.9). The user can analyse either transient regime, or steady state operation. Only the steady state data processing is detailed in this paper. The steady state analysis can be carried out for each steady state operation point both at the network side (by the Network… sub-menu) and at the motor side (by the Motor… sub-menu).

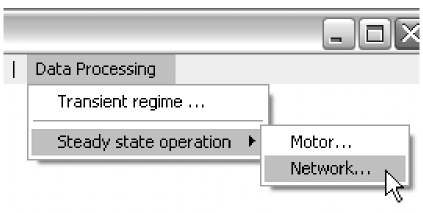

Fig.9 The data processing pull-down menu

3. Power quality assessment possibilities

The power quality analysis can be done on the basis of some synthetic indices. These factors depend on the powers circulating in the system.

All specialists agree with the fact that, under nonsinusoidal conditions, the active (P), reactive (Q) and apparent (S) powers are not in the same relation as under sinusoidal conditions, respectively

$$S^2 \neq P^2 + Q^2 . \tag{1}$$

The active power is defined as the average value of the instantaneous power over one cycle T of the voltage and current signals, namely

$$P = \frac{1}{T}\int_0^T u(t)i(t)dt . \tag{2}$$

In the frequency-domain, the definitions of P and S were accepted since 1927, when Professor C. Budeanu introduced [7]:

$$P = 3\sum_{k=1}^{\infty} U_k I_k \cos\varphi_k , \tag{3}$$

$$S = 3UI = 3\sqrt{\left(\sum_{k=1}^{\infty} U_k{}^2\right)\left(\sum_{k=1}^{\infty} I_k{}^2\right)} , \tag{4}$$

where k is the harmonic order, U_k and I_k are rms values of phase voltages and currents and φ_k is the phase displacement between them.

But, the reactive power defined by Budeanu,

$$Q_B = 3\sum_{k=1}^{\infty} U_k I_k \sin\varphi_k , \tag{5}$$

was disputed.

Professor L.S. Czarnecki is one of the specialists who emphasised the imperfection of the Q_B and proposed a new definition for the reactive power [8]:

$$Q_C = 3U\sqrt{\sum_{k=1}^{\infty}\left(I_k \sin\varphi_k\right)^2} . \tag{6}$$

Another efficient instrument is the phasorial theory of the powers introduced by Professor V. Nedelcu [9] and developed by Akagi and Nabae [10] and then by other specialists [11], [12].

Considering that u_d, u_q and i_d, i_q are the components of the representative voltage and current phasors, the active and the reactive powers are:

$$P_f = \frac{1}{T}\int_0^T \frac{3}{2}\left(u_d i_d + u_q i_q\right)dt , \tag{7}$$

$$Q_f = \frac{1}{T}\int_0^T \frac{3}{2}\left(u_q i_d - u_d i_q\right)dt . \tag{8}$$

The distortion power (also termed "deformation power") is obtained depending on the definitions of the other powers:

$$D = \sqrt{S^2 - \left(P^2 + Q^2\right)} . \tag{9}$$

Thus, the energetic analysis can be performed on the basis of the next power quality indices.

1. The total harmonic distortion factor of the current:

$$THD_i = \sqrt{1 - \left(I_1/I\right)^2} , \tag{10}$$

or

$$THD_i = \sqrt{\left(I/I_1\right)^2 - 1} , \tag{11}$$

where I_1 and I are the fundamental component and the rms value of the current.

2. The global power factor,

$$PF = P/S . \tag{12}$$

3. The displacement power factor

$$DPF = \cos\varphi_1 ; \tag{13}$$

4. The distortion power factor

$$DF = D/S \,. \tag{14}$$

4. Power quality assessment examples

To illustrate the graphical user interface facilities for power quality assessment, a case study of the electrical drive with induction motor and harmonics cancellation inverter fed by a three-phase rectifier is presented.
In this example, the simulation was carried out for twenty four steady state operation points corresponding to four frequencies and six load torques.
The following examples are some of the results of data processing both at the network side and at the motor side. These correspond to steady state operation of the power system at inverter fundamental frequency of 20Hz and load torque of 10Nm.

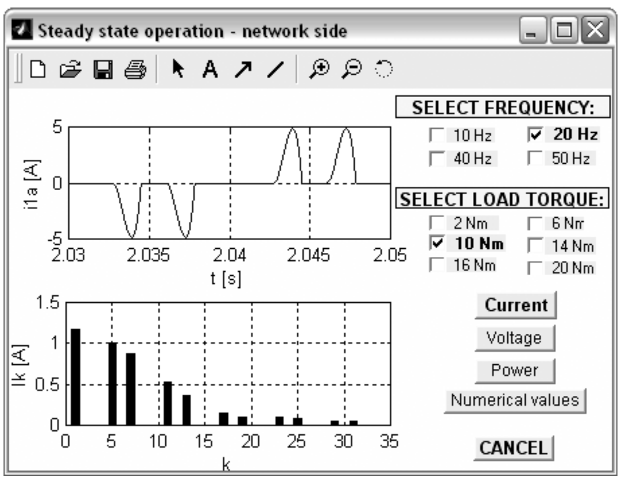

Fig.10 The network current and its harmonics spectra

4.1. Network side

In Data Processing menu, the selection of Network item of Steady state operation ► sub-menu (Fig.9) displays its own window labeled “Steady state operation – network side” (Fig.10). A set of four buttons are provided for user input. Thus, the user is able to obtain information on the currents, voltages, powers and the indices of power quality.
So, if the user selects a frequency and load torque and then he clicks on the Current button, a one-cycle current waveform and its harmonics spectra are displayed (Fig.10). As it can be seen, the current waveform is much distorted and the harmonics are higher, because the drive rectifies the incoming supply.
In the same manner, by clicking on the Power button, the user is able to display the waveforms of the instantaneous power and its spectra of harmonics (Fig.11).

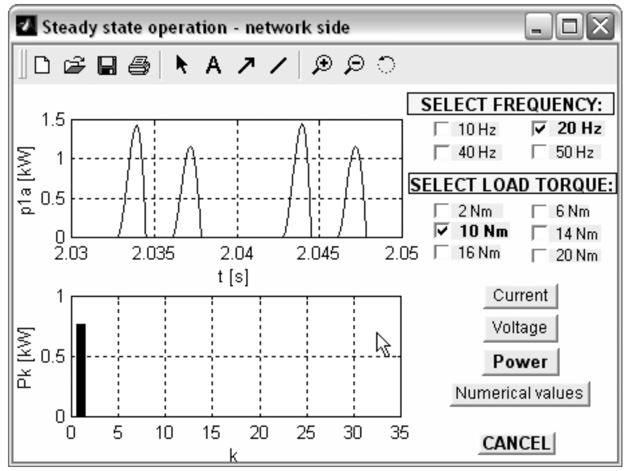

Fig.11 The network instantaneous power and its harmonics spectra

The Numerical Values button is used to display the information for the selected steady state operation point (Fig. 12).
The summary information (inverter frequency, load torque, rms voltage, rms current) is included. For the quantities for which there are more computing possibilities in accordance with the actual teories, it is possible to select the appropriate option from a popup menu. In the adjoining text field the new result will be displayed. There are more displaying possibilities as follow.
- For the active power: instantaneous power average (2), harmonics theory (3) or phasorial theory (7).
- For the reactive and distortion powers: Budeanu’s theory (5), Czarnecki’s theory (6) or phasorial theory (8).
- For the global power factor: either harmonics theory or phasorial theory according to the active power computing.
- For the total harmonic distortion factor: referred either to the total rms value (10) or to the rms value of the fundamental component (11).
A detailed tabular display is also given for the voltage, current and power harmonic spectra.

4.2. Motor side

In Data Processing menu, if the user clicks on Motor item of Steady state operation ► sub-menu (Fig.9), the window named “Steady state operation – motor side” will be displayed.
The harmonics cancellation modulation strategy chosen for the voltage inverter makes all harmonics of an order less than 19 to be practically eliminated from the voltage waveform (Fig.13).
In accordance with the harmonics cancellation principle, by reversing the phase potentials a number of times during each half-cycle, the spectra of harmonics can be changed in such a way that some low order harmonics, which can be troublesome to the load, are cancelled, whereas some high order harmonics, which are less harmful, increase in amplitudine [13], [14].

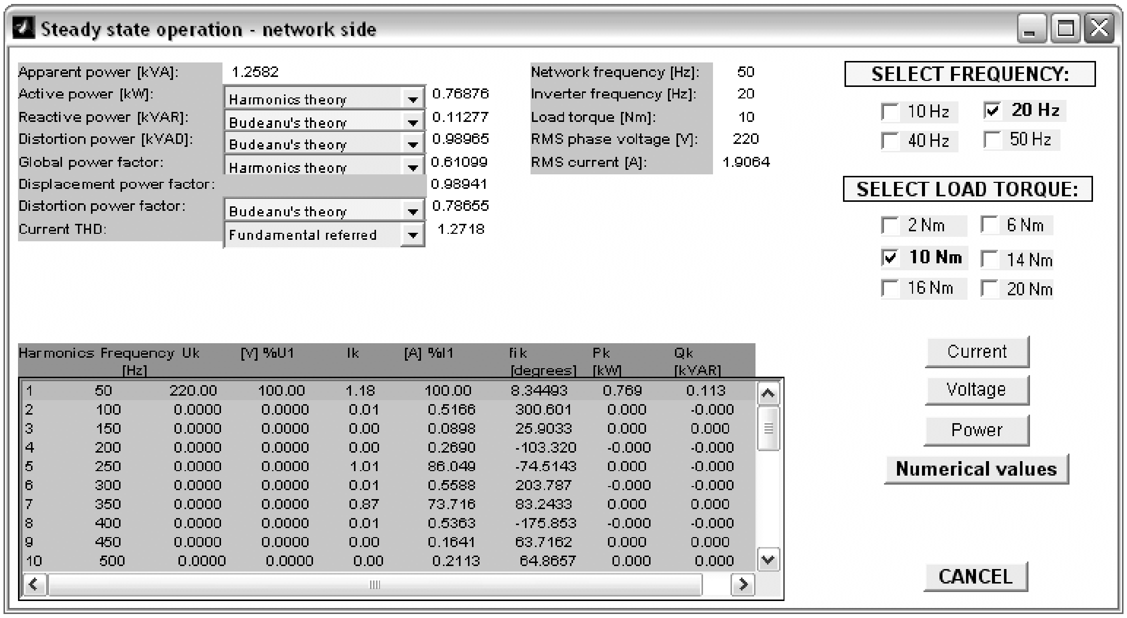

Fig.12 The Numerical values window – the network side at 20Hz and 10Nm.

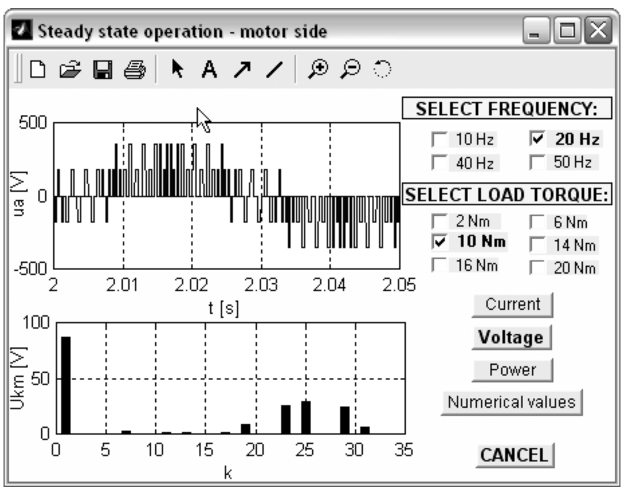

Fig.13 The output phase voltage and its harmonics spectra

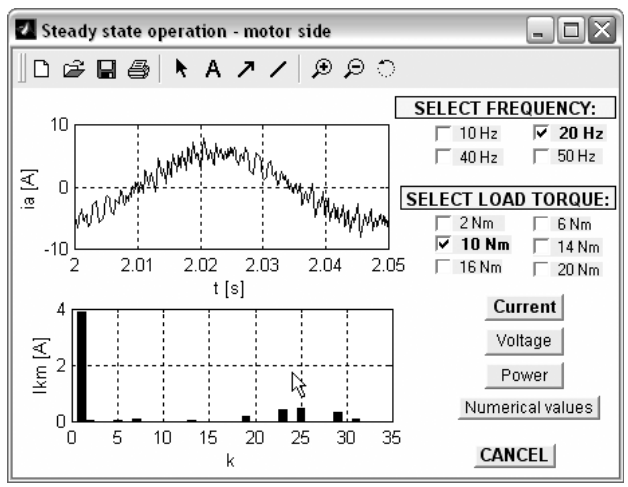

Fig.14 The load current and its harmonics spectra

As a high frequency overmodulation signal must be superposed on the precalculed waveform in order to adjust the output rms voltage, the low order harmonics are insignificant but non zero (Fig.13).

The load current of the asynchronous motor and its harmonic content are reported to the user by clicking on the Current button, in order to illustrate the effect of canceling harmonics (Fig.14).

The instantaneous power at the motor side is displayed by a click on the Power button (Fig.15).

If the user needs the numerical values describing the steady state operation point, the Numerical values button must be pressed and than an appropriate window appears (Fig.16).

Next to the quantities which appears in the similar window for the network side (Fig.12) there is the information on the angular speed, electromagnetic torque and motor efficiency.

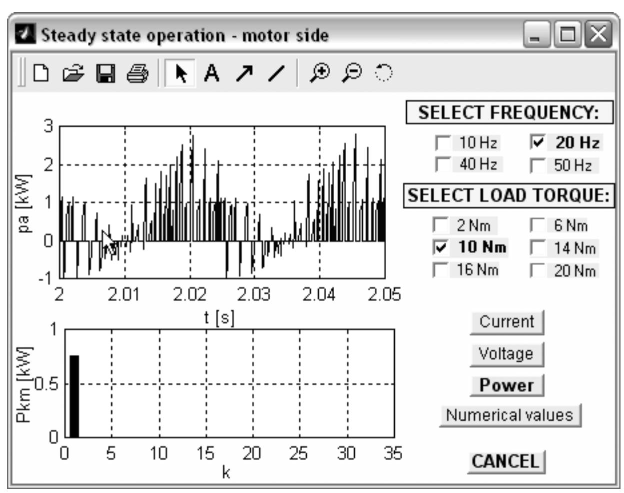

Fig.15 The load instantaneous power and its harmonics spectra

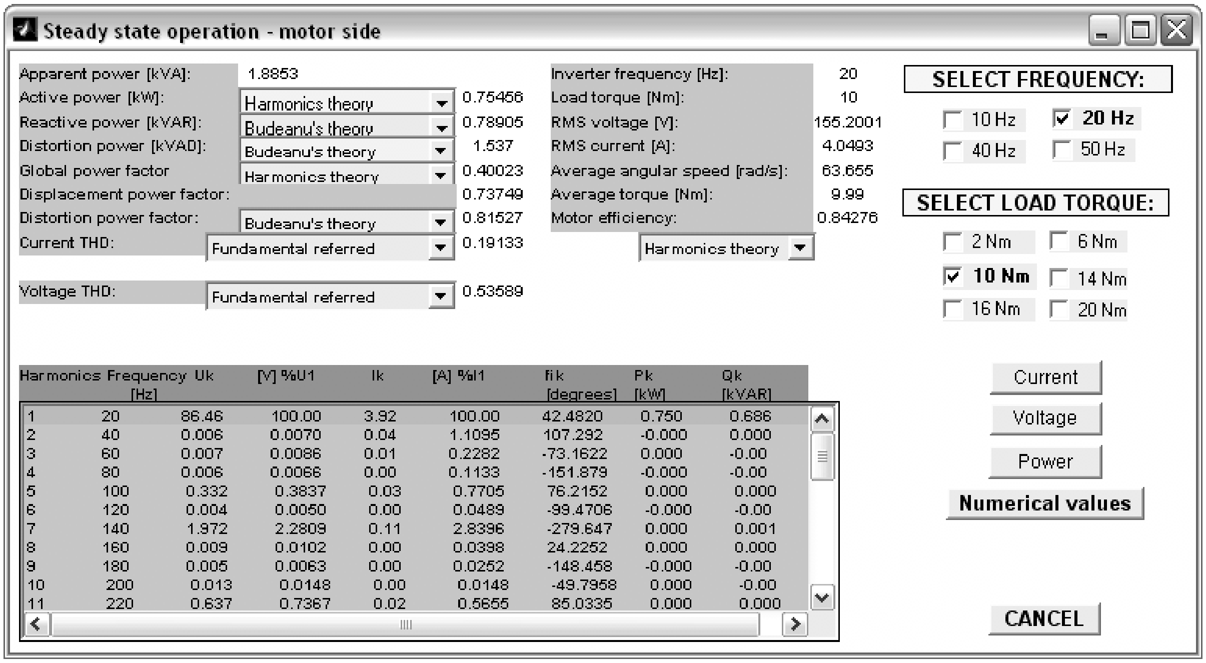

Fig.16 The Numerical values window – the motor side at 20Hz and 10Nm.

5. Conclusion

The new friendly graphical user interface is a useful tool for power quality assessment in induction motor and static converter driving systems.

This interface allows users to simply configure the system structure and parameters as well as the control strategy of the system.

The simulations followed by power quality analysis can be used as educational tools in finding both the system parameters influences and the control strategies influences on the power quality performances in the power system.

It can be noticed that it is possible to simply add other extensions concerning the modulation strategies of the voltage inverter and the induction motor control. Further options in power term definitions can easily be added too.

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