Integration of harmonic flow analysis software with database of non-linear loads

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Abstract **Paper presents algorithm for frequency model estimation of non-linear loads. Algorithm takes time based waveforms (current, voltage) from the database (PostgresSQL) and using one of the Fourier analysis methods evaluates the amplitude-frequency and phase-frequency characteristics of the load. These characteristics can be used in further frequency analysis (Matlab/PCFLO) of a power network containing non-linear loads. Performed tests showed that the signals should be sampled synchronously with the signal base frequency or this frequency must be determined with high accuracy to obtain reliable results.**

Keywords **harmonic flow analysis, frequency analysis, Matlab, PCFLO, PostgresSQL**

I. Introduction

The paper brings up some issues related to voltage and current harmonic flow modelling in selected fragments of power network. Because there are no standard test networks for that purpose in Poland [4], authors used some worldwide available suggestions for such systems. In this paper an exemplary test network proposed by W.M. Grady [2] has been used.

There are many analysis methods allowing current and voltage harmonic flow analysis in the networks containing non-linear loads [1]. One of the most popular is the frequency analysis. Because of the power network complexity it is usually necessary to simplify the analysis methods and/or network element models. In many cases all non-linearities present in the system are neglected. With this assumption, to keep the information about higher harmonics, all currents and voltages are expanded to Fourier series. Next step is to calculate the dependencies between voltage, current and impedance of every network element for each harmonic separately. The result of that analysis are amplitude-frequency and phase-frequency characteristics of the system which can be used, for instance, to calculate THD (Total Harmonic Distortions) of voltages and currents. Presented frequency analysis method can be performed when the waveforms in the system are periodic.

II. Active power filter placement

Present authors researches are focused on finding methods for optimal placement of APF (Active Power Filters) in the chosen fragments of power network. To achieve this task a software package combining Matlab and PCFLO to work together has been prepared.

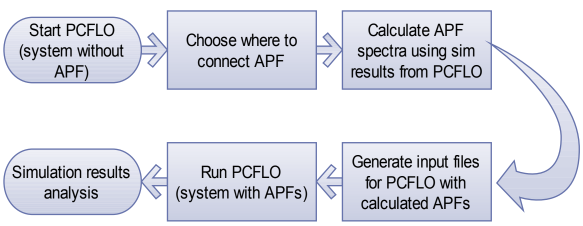

Fig. 1. Harmonic flow analysis with APFs using Matlab/PCFLO

Matlab provides optimization algorithms and pre/post processing and PCFLO allows to calculate harmonic flow in the system using the frequency method. Exemplary block diagram of Matlab/PCFLO cooperation has been shown in fig.1. As a result of already carried out researches a test network model has been implemented and a frequency model of APF has been prepared. The APF model has been prepared as a result of detailed analysis of a time based model [5].

To be able to asses the APF's effectiveness, it is necessery to check the network behavior for different non-linear load types and parameter values. To achieve this task a database system with measurement data of different non-linear loads has been prepared. Current and voltage waveforms can be directly loaded into the database from files generated by Tektronix digital osciloscopes or from „.csv“ files. The database has a dedicated GUI accesible via „http“ protocol, so the data can be loaded remotely using the Internet. GUI also icludes some analysis and visualisation capabilities.

To be able to use the data from the database in Matlab/PCFLO it is necessary to prepare and implement algorithm which extracts the waveforms stored the database, prepares frequency model of a chosen load and writes the model in the PCFLO format.

III. Load model estimation algorithm

Algorithm of frequency model estimation has been shown in fig.2.

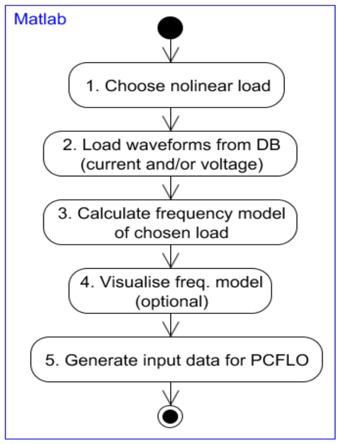

Fig. 2. Algorithm of load's frequency model estimation

In a first step, a non-linear load is chosen from the database. Then the measured waveforms of current and voltage are loaded from the database to Matlab. In the third step, the frequency model of given load is estimated. This is the the critical operation and it is discussed in the next paragraph. When the frequency model is evaluated it can be visualised to asses the results (stage 4). The last step is to save the frequency model in the PCFLO format.

Steps 1-4 of the algorithm has been implemented in Matlab. To connect to PostgresSQL database, the Matlab Database Toolbox was used. For convenience (lack of advance text operation functions in Matlab) step 5 was implemented directly in the Java language.

IV. Frequency model estimation details

To evaluate the frequency model of a chosen non-linear load, the expansion to Fourier series can be used [1]. To use this technique two assumptions must be fulfilled:

1. The waveforms must be periodic.
2. The waveforms base frequency must be equal to 50 Hz (in Europe) or determined with high accuracy.

Both assumptions has been validated for power network current and voltage waveforms. The conclusions are:

1. When we do not consider interharmonics and take the loads as quasi-stationery [6], the assumption can be taken as true.
2. Because of the power network frequency swing [3] the second assumption is usually not true.

To show how the frequency swing influences the Fourier series coefficients, expansion of an exemplary current waveform with known Fourier series has been performed for signals with frequency range from 48 to 52 Hz [3]. Then the THD error connected with the frequency swing has been evaluated. The THD error has been defined as follows:

$$THD_{error} = \frac{\sqrt{\sum_{i=2}^{40} |F_i' - F_i|^2}}{|F_1|} \cdot 100\,\% \qquad (1)$$

where:

$|F_i'|$ – correct RMS of i-th harmonic (voltage/current),

$|F_i|$ – evaluated Fourier RMS of i-th harmonic.

Results of the performed Fourier expansion with assumed constant frequency of 50 Hz are shown in fig.3.

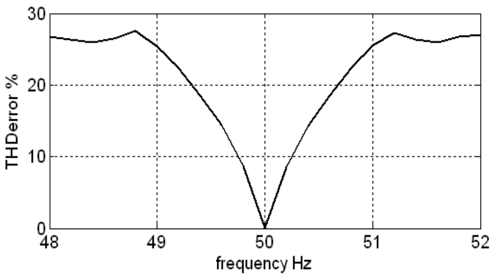

Fig. 3. Example of THD error versus base frequency

As can be noticed in fig.3, the THD error strongly depends on the frequency swing and even small frequency changes can influence the THD results. In other words, the results are accurate when the base frequency is determined with high accuracy.

Alternative method to the Fourier series expansion is the Discrete Fourier Transform (DFT). In this case another problem exists called the transform leakage [1]. However, this phenomena can be eliminated or at least reduced [1]. There are two cases:

1. When the sampling frequency is synchronized with the base frequency and the recorded signal contains integer number of whole signal periods. In this case the leakage is completely eliminated[1].
2. When the sampling frequency is not synchronized, the leakage can be minimized by using the windowing function different then rectangular, for example the Hanning window [6]. However, the frequency grid should still be matched as close as possible to the base frequency sacrificing the "whole period" rule.

Both methods has been implemented and can be chosen according to the recorded data. Preferred are synchronized signals and such measurements should be done when it is possible. Recommended parameters for synchronized signals recording are [6]: number of recorded periods K=8 and DFT size N=1024 points. For base frequency equal 50 Hz it gives the frequency grid resolution of 6,25 Hz. Unfortunately to determine the correct DFT size it is necessary to know the actual base frequency [6] just like in the Fourier series method. Nevertheless, for discrete signals the DFT is faster and easier in numerical implementation than the Fourier series expansion (DFT avoids numerical integration). Both methods has been tested on exemplary signals from the database.

V. Conclusions

Presented algorithm allows to transform time based waveforms from the database to frequency model of non-linear loads. The model can be used in Matlab/PCFLO environment. The critical part of the method is the Fourier coefficients evaluation. For sampling frequency synchronized with the waveform base frequency and integer number of recorded periods, the DFT leads directly to correct results. In other cases the base frequency must be determined and the DFT is preferred because of numerical implementation advantages.

VI. Acknowledgements

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VII. References

[1] Arrillaga J., Watson N.R..: "Power system harmonics, 2nd edition", John Wiley & Sons Ltd., Chichester, England, 2003.

[2] Grady M.: "Understanding power system harmonics", Dept. of Electrical & Computer Engineering, University of Texas at Austin, June 2006 (http://users.ece.utexas.edu/~grady/).

[3] Kowalski Z.:"Jekość energii elektrycznej", Wydawnictwo Politechniki Łódzkiej, Łódź, 2007.

[4] Maciążek M., Lewandowski M., Pasko M.: "Systemy testowe dla potrzeb analizy harmonicznych w układach zasilających zawierających energetyczne filtry aktywne", Energetyka nr 10/2010 (644), Oficyna Wydawnicza Energia COSiW SEP, Katowice, October 2010, pp.656-660.

[5] Maciążek M., Grabowski D., Lewandowski M.: "Analiza rozpływu harmonicznych w układzie z energetycznym filtrem aktywnym" Kwartalnik Elektryka 2011 (in print).

[6] PN-EN 61000-4-7, Electromagnetic compatibility (EMC), part 4: Testing and measurements techniques, section 7: General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and connected equipment, PKN, December 1998.