THE MAKING AND PURPOSE OF HARMONIC FINGERPRINTS

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ABSTRACT

In most software packages for harmonic calculations in the grid, harmonic currents of devices are modeled as harmonic current source. However, in practice there is hardly any good description of the harmonic behavior of a device or an installation. Sometimes there is some information available about the harmonic currents injected in the situation where the device is connected (conform the standards) to an undistorted supply voltage. But this is not the situation in the normal grid. So, there is a necessity to get more reliable and accurate data for harmonic calculations. Presented is a way to make a harmonic fingerprint of a device or a total installation. Within this fingerprint also the interaction between the distorted supply voltage and the harmonic current will be defined.

MAKING THE FINGERPRINT

An important problem what has to be tackled is to get knowledge on the interaction between the harmonic voltage and the harmonic currents. Devices are, according to the appropriate standards, tested with an undistorted voltage. Possible interaction with harmonic voltage distortion which can lead to undefined harmonic currents, is not included in the standard [1]. To get more insight in this interaction the following measurement system as already used for PV-inverters [2,3] is used for all kind of loads.

The schema as shown in figure 1 than can be used to identify the harmonic currents with and without harmonic background voltage.

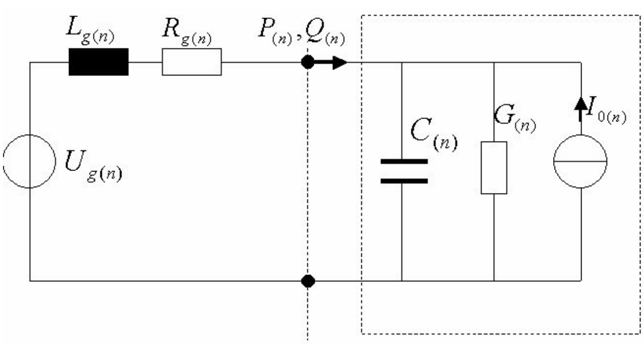


Figure 1: Simple schema with load connected to the network

The symbols used in the schema are:

U_g = the grid background harmonic voltage distortion
R_g = the grid resistance, including skin-effect
L_g = the grid inductance
Io = the harmonic current emission of the load without background distortion
C = the capacitance of the load
G = the total conductance of the load
P = Active power connection point (for calculating G)
Q = Reactive power at connection point (for calculating C)

The measurement is done as displayed in figure 2, and described in more detail in [3]. In first instance, the load is connected to an undistorted voltage, so producing the fundamental current and the Io as shown in figure 1. This harmonic current emission of the load can be measured. Secondly, on the supply voltage is added a distortion with the 3rd harmonic voltage varying from 0.5% to 5% and a phase shift from 0° till 360°. The respond of the harmonic current is measured for each situation. This procedure is donning for each harmonic voltage as shown in figure 2.

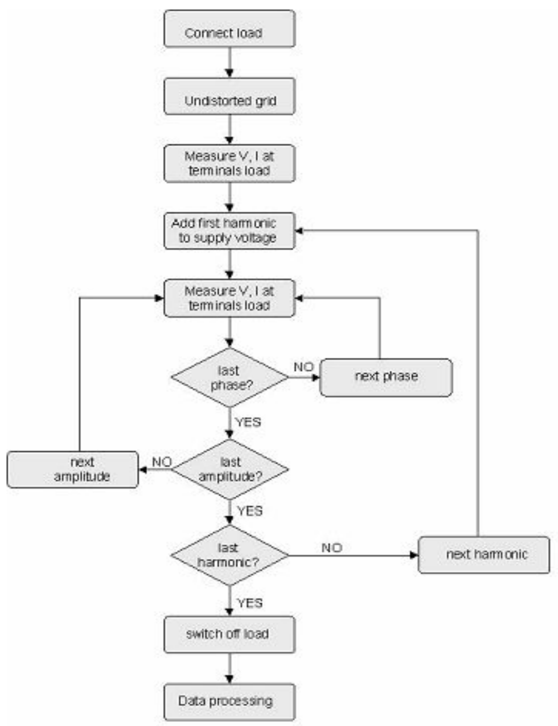


Figure 2: Procedure to measure harmonic current and harmonic interaction

To explain the method and to show the response on harmonic voltage of passive components, the results of measuring a capacitor will be given. Figure 3 shows the results of a capacitor, corresponding with a 1 kvar load at 230 V. The first picture is the harmonic voltage put on to the capacitor. All bullets are harmonic voltages which where added to the fundamental voltage with the given amplitude and phase. The harmonic current response on this harmonic voltage is given in the second picture. The thicker bullets in the two pictures correspond with each other. So, the harmonic current is linear with the harmonic voltage and with 90 degrees phase shift, as expected.
The value of $G_{(n)}$ can be calculated with these voltages and currents and will be 0 for each harmonic and each amplitude and phase due to the 90 degree phase shift. The harmonic active power is zero, what means that $G_{(n)}$ =0, for each harmonic. By calculating the $C_{(n)}/C_{ref}$ it shows that this value is 1, for each harmonic. (It is more practical to use a normalized value of the capacitance. Therefore $C_{(n)}$ will by divided by C_{ref}, which is defined as the value of the capacitor that would carry the same current as the inverter at nominal power, for more information [3]).

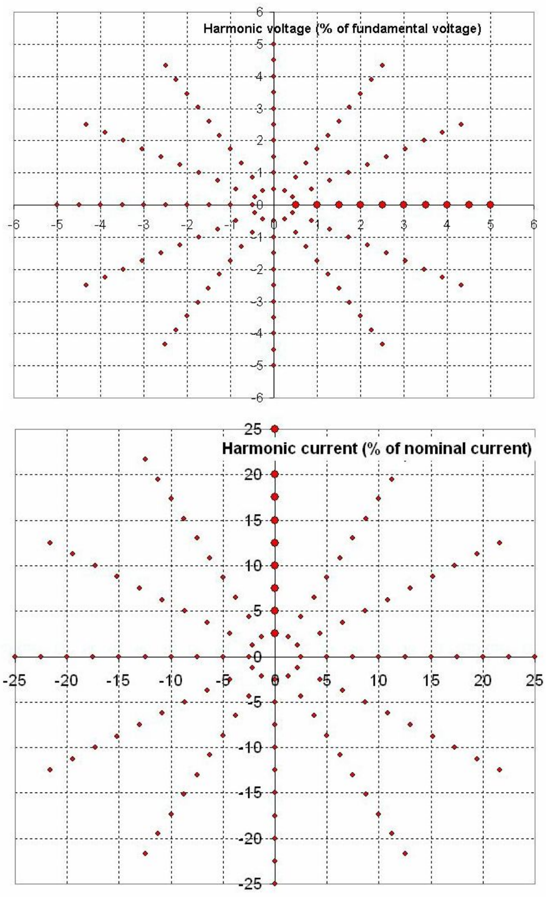


Figure 3: Harmonic voltages and current interaction capacitor for 5th harmonic

Important features of the capacitor are:

- There is no harmonic current when the harmonic voltage is zero. So, there is no harmonic current source *Io*.
- There is a linear behaviour between voltage and current.
- There is no interaction between the harmonics (5th harmonic voltage only gives a 5th harmonic current and no currents of other frequencies).

Harmonic calculations in grids with only passive components are for this reason not as complex as calculations in grids with components which do not have these features.

LINEAR BEHAVIOUR

To limit the amount of data for each device it is interesting to know of devices act in the frequency domain as a linear load or source. If this is the case then the value of G and C, according figure 1 will be constant for a given frequency. The principle of linearity is shown in figure 4.

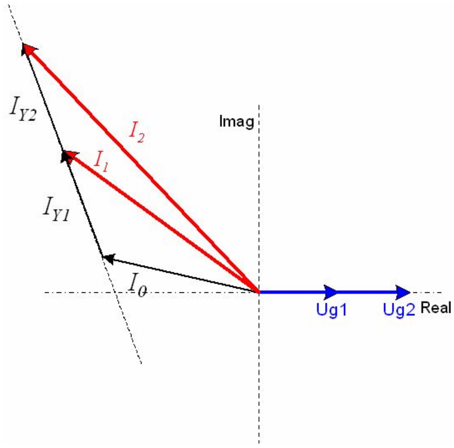


Figure 4: Linear behaviour

In the figure *Io* is the current produced by the device when there is no harmonic distortion in the supply voltage. When in the supply voltage at a certain frequency a harmonic voltage *Ug1* occur, there will flow a current trough the conductance G and the capacitor C, given as I_{Y1}. The total harmonic current will be I_1. When the value of the harmonic voltage will double to *Ug2*, the current trough G and C will double leading to I_{Y2} and a total harmonic current of I_2.

A second feature of linear behaviour is illustrated in figure 5. Again *Io* is the current produced by the device when there is no harmonic distortion in the supply voltage. When in the supply voltage at a certain frequency a harmonic voltage *Ug1* occur, there will flow a current trough the conductance G and the capacitor C, given as I_{Y1}. The total harmonic current will be I_1. When the phase angle of the harmonic voltage changes, the phase angle of the current trough G and C will change accordingly leading to I_{Y2} and a total harmonic current of I_2.
The third feature of linearity is zero cross-interference. With

zero cross-interference is meant that a n^{th} harmonic voltage will only give a reaction on the n^{th} harmonic current, and not at other frequencies. To quantify the influence of harmonic voltage on other harmonic currents, the standard deviation of all harmonic currents per set of measurements is calculated.

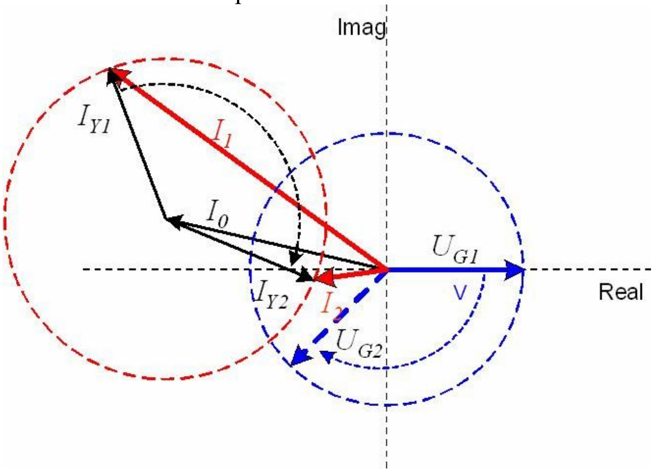


Figure 5: Second feature of linearity, phase angle shift

When there is no influence, the standard deviation is zero. Figure 6 shows an example of a plot where deviations for all harmonics are plotted. The crosstalk-ratio is defined as the ratio between the highest and the second highest deviation. The deviation of the harmonic that is changed throughout the different voltage set points is generally the largest. A high ratio indicates better frequency decoupling.

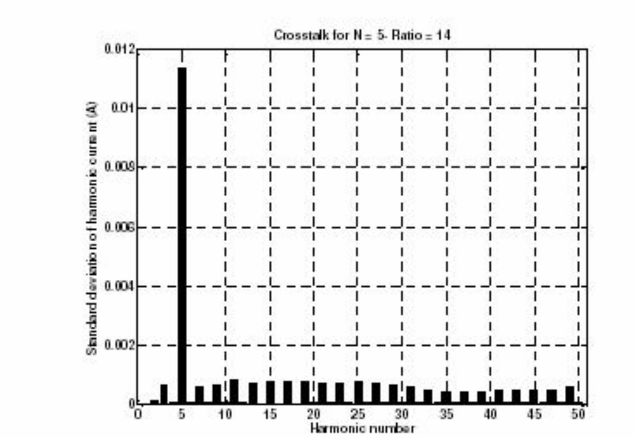


Figure 6: Example of plotting the cross-interference

In practice, some devices will have behaviour near to linearity, but some deviations can be possible. Nevertheless, it can be useful to use one expression for Y (or G and C) for each harmonic number.

ENERGY SAVING LAMP

The power utility companies worldwide promote the use of energy-saving lamps [4]. The most common type of such lamps is the self-ballasted compact fluorescent lamp with electronic gear. However, that type of lamp is a highly non-linear load producing an extremely distorted current with a total harmonic distortion (THD) usually exceeding 100%, as shown in figure 7. This picture however, doesn't show the influence of an already distorted supply voltage.

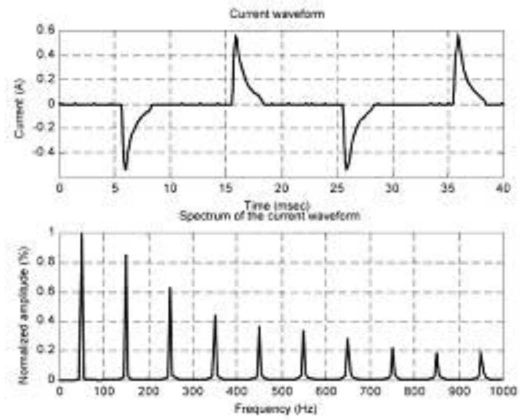
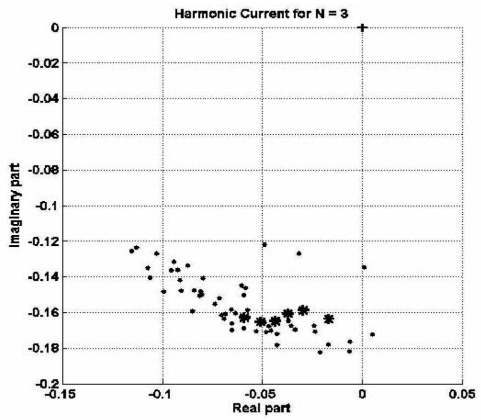


Figure 7: Current waveform of energy saving lamp with electronic gear (ideal)



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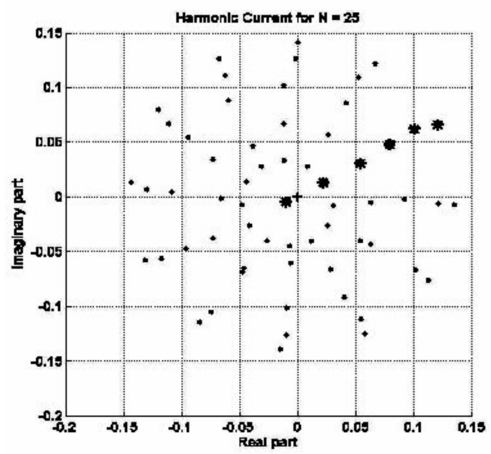

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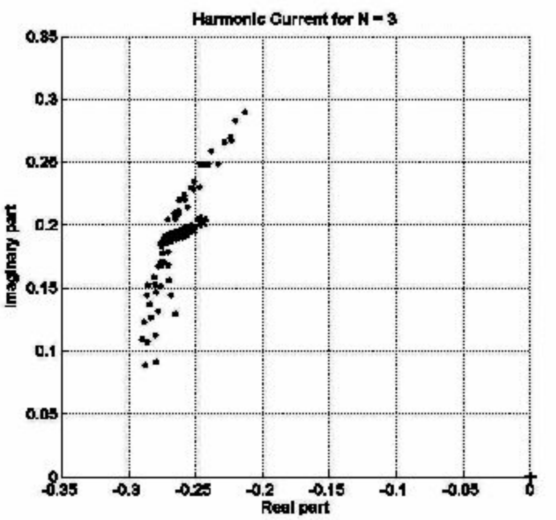
Figure 8 a/b: Harmonic fingerprint of energy saving lamp for 3^{rd} and 25^{th} harmonic

What is happening when a distorted voltage is put on to the lamp is shown in figure 8a for a 3rd harmonic distortion and figure 8b for a 25th harmonic distortion The connected harmonic voltage is as in the previous section varying from 0.5% to 5% of the fundamental voltage and a phase shift from 0° till 360°. The 3rd harmonic current without any distortion in the supply voltage is I3o=-0.06-j0.16 A. The basic 25th current I25o is almost zero. Introducing a harmonic distortion on the 25th harmonic frequency shows a linear behavior in the lamps current.

PERSONAL COMPUTER

Another, very often used device is the personal computer. Almost every household will be using one or more of these devices. Also the simultaneously use of the personal computer is increasing which makes it interesting to measure the harmonic fingerprint. In figure 9a en b again the 3rd and 25th harmonic reaction on a distorted voltage is presented.



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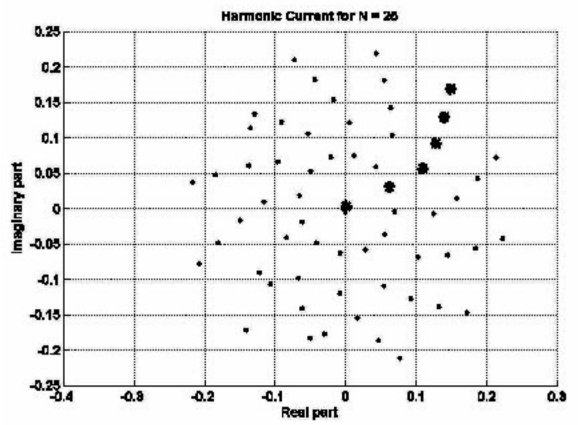

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Figure 9a/b: Harmonic fingerprint personal computer for 3rd and 25th harmonic

The pictures have some similar characteristics as those from the energy saving lamp. On the entrance of both devices is placed a rectifier, which is mainly responsible for the reaction. By analyzing the behavior of a general rectifier also the cross interference has been shown an issue which has to be taken into account when accurate calculations of harmonic voltages and currents are needed. This makes it complicated to use a simple model of G and C. The best solution is to store the measured data in a matrix, which can be used for calculations. So, the complete fingerprint has to be used as parallel current sources, instead of simple values of G and C.

CONCLUSIONS

To make accurate calculations of harmonic voltages and currents in the grid, harmonic fingerprints of devices connected to it are needed. Also for analyzing the design of a device it makes sense to measure the harmonic fingerprint to study the interaction of the device on harmonic voltages.
The introduction of more power electronics gives an increase of the harmonic distortion, as seen several times by using inverters for connecting dispersed generation to the network. This can be avoided by making proper standards, so that manufacturers of these inverters are able, without commercial constraints, to develop higher qualified inverters which limit the harmonic currents. In this way harmonic distortion of the supply voltage can be limited or even reduced. Making a harmonic fingerprint for each device is time consuming but it can be very helpful in designing a device. Devices should be robust for harmonic distortion of the supply voltage and should give a limited reaction on this distortion leading to a further distortion. For testing purposes (needed for a standard), making a full fingerprint is perhaps possible for type tests. Tests which have to be done on each device could be limited to test the device, using a "test distortion" which is comparable with the average distortion of the supply voltage in the network

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