



SIMULATION OF NON-LINEAR LOAD

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ABSTRACT

This paper introduces one possible way to create of nonlinear loads in DYNAST program. Processes that are carried out when doing this creation are described. Next, the paper approaches possible faults that occur when creating particular network elements in DYNAST. At the end, harmonics current waveforms for two chosen nonlinear loads with the evaluation of their influence on supply voltage and current are described.

Keywords

Nonlinear load, current waveform, harmonics, voltage distortion, DYNAST

• **INTRODUCTION**

There is a broad range of electric elements in households, institutions or industrial companies. These appliances consume a variety of large currents with different shapes when supplied from the harmonic power source. Some of them consume sinusoidal currents of frequency 50 Hz (so-called nominal frequency), that has some amplitude and phase angle compared to supply voltage. Other appliances consume currents of frequencies higher than 50 Hz. These currents are called “harmonics” and they are consumed by nonlinear loads. A Consumed frequency is not usual only one. They consume currents of higher frequencies higher than 50 Hz that are the whole multiple of nominal frequency. Harmonics are transmitted into the power system from the loads and therefore consumed non-harmonic current occurs in the supply system. An occurrence of harmonics is undesirable. Harmonics cause additional voltage drops on individual impedances in the power system. These voltage drops lead to the distortion of voltage waves with ideal sinusoidal waveform and therefore they decrease the quality of supply voltage. They also cause heating of cable insulations, transformers and other devices of the electric power system which results in higher power losses. Moreover, they influence protections action, generate noise and thus can affect nearby telecommunication and other electronic devices.

• **INPUT DATA FOR NONLINEAR LOAD SIMULATIONS**

It is possible to use a several approaches for simulating of nonlinear load. The first of them can be applied when V-A characteristic of the specific load is known. This way is almost unrealizable because no company usually specifies such information about their products. The next possibility is to know consumed harmonics spectrum. This information is also very difficult to obtain since again producers do not publish these data. The last way is usage of real waveforms of consumed currents that are indicated by individual measurements with appropriate data processing. In Fig. 1, measured current waveform for harmonic sinusoidal voltage of television set is presented. From current waveform is evident that consumed current is approximately zero within a certain time interval. In the remaining time section, the waveform is almost sinusoidal with higher frequency and zero,

respectively. The whole procedure and model creation is performed for this appliance in program DYNAST.

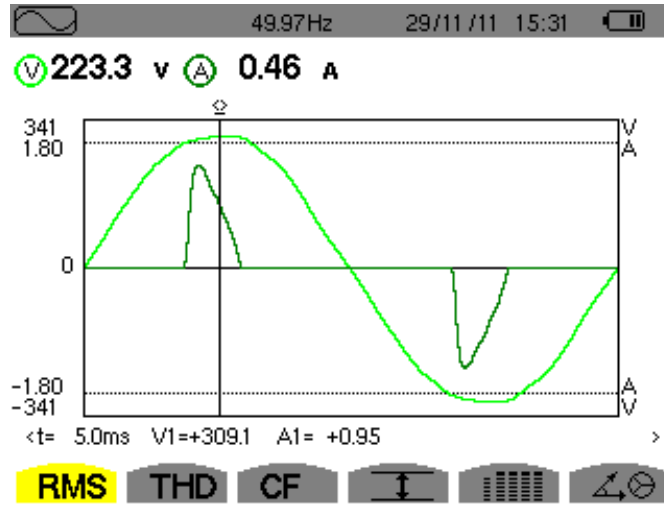


Figure 1 – Current and voltage waveforms of television set

• **NONLINEAR WAVEFORM SIMULATION**

First, it is necessary to create similar waveform of transmitted current under sinusoidal voltage supply. Created waveform has to correspond to the shape of the current curve and ensure its limitation around time instants when the waveform is approximately zero. All requirements are ensured by means of transformed limited sinusoidal function with appropriate frequency. This function enables us to create the waveform that will have given magnitude, period, shape and time instants for its zero value and derivation for ensuring zero waveform before and after appropriate times. In the case, that this waveform can not be created using only one function, it is necessary to assemble together more similar functions that will correspond to the next time intervals or second half period of voltage time function.

$$u=230*\sqrt{2}*\sin(2PI*50*time);$$

$$f1 /SIN/ B=25, C=2PI*150, L=13.333m, U=16.666m, SL=0, SU=0, P=20m;$$

$$f2 /SIN/ B=-25, C=2PI*150, L=3.333m, U=6.666m, SL=0, SU=0, P=20m;$$

These limited functions are necessary to be assigned to other variables that are dependent on the time. Resulting function is only the sum of particular functions (Fig. 2).

$$i1(t)=f1(time); i2(t)=f2(time); i(t)=i1(t)+i2(t);$$

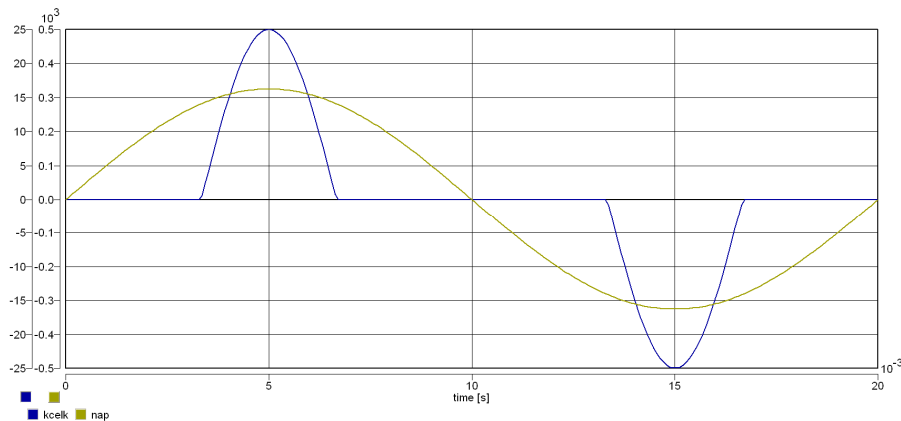


Figure 2 – Non-harmonic current created by the transformed function

• **DATA EXPORT**

For nonlinear load creation, when consumed current is dependent on the supply voltage, it is necessary to export the data into suitable program, where this dependence is detectable. One such suitable program is MS Excel, where the V-A characteristics can be suitably constructed. The advantage of MS Excel is that individual values of current and voltage correspond to concrete value of time when performing simulations in DYNAST. Therefore, there are no time shifts or no time consuming hand values rewriting. An accuracy of V-A characteristic creation depends on the amount of exported data, i.e. on chosen time step size of the calculation in DYNAST.

<i>X ... time [s]</i>	<i>I ... i=f(t)</i>	<i>2 ... u=f(t)</i>
<i>X</i>	<i>I</i>	<i>2</i>
<i>0.000000e+000</i>	<i>-1.554504e-011</i>	<i>0.000000e+000</i>
<i>4.000000e-005</i>	<i>-1.554504e-011</i>	<i>4.087337e+000</i>
<i>8.000000e-005</i>	<i>-1.554504e-011</i>	<i>8.173939e+000</i>
<i>1.200000e-004</i>	<i>-1.554504e-011</i>	<i>1.225922e+001</i>
.....		
<i>3.760000e-003</i>	<i>9.790482e+000</i>	<i>3.008932e+002</i>
<i>3.800000e-003</i>	<i>1.065047e+001</i>	<i>3.024217e+002</i>
<i>3.840000e-003</i>	<i>1.149534e+001</i>	<i>3.039024e+002</i>
<i>3.880000e-003</i>	<i>1.232388e+001</i>	<i>3.053352e+002</i>

There are several ways for creating of V-A characteristics in Excel program. Suitable projection type is the line graph with displayed regression equation. This regression can be variable with the shape of the power function. The most appropriate is the linear dependence because it is the simplest (Fig. 3). It is very important to continually update the values from which the regression equation is created because otherwise obtained function may not correspond to the actual waveform. Mistakes occur especially in the initial and final points of the current waveform. Moreover, small errors arise influence of linear regression. It affects especially the current amplitude.

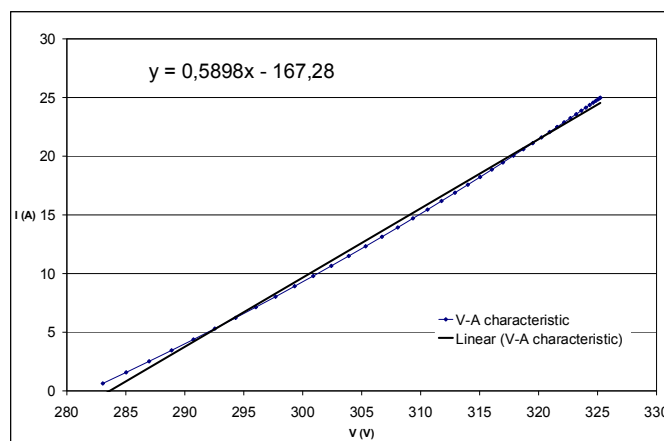


Figure 3 - Load characteristic with linear regression

• **NON-LINEAR CHARACTERISTIC CREATION**

In DYNAST program, is necessary to create the transformed limited linear function which will respect obtained current for certain voltage value. Time instants, up to which the waveform is zero, are necessary to be specified using the derivations of function (Fig. 4). These functions must be assigned to other functions that are dependent on voltage at the given point (for this case in point A). Resulting dependence is given by the sum of individual linear functions that are voltage-dependent.

$g1 /LIN/ A=-167.28, B=0.5898, L=283.621568, SL=0, U=350;$

$g2 /LIN/ A=167.32, B=0.5898, L=-350, U=-283.689388, SU=0;$

$b1(u)=g1(A);$

$b2(u)=g2(A);$

$icelk=b1(u)+b2(u);$

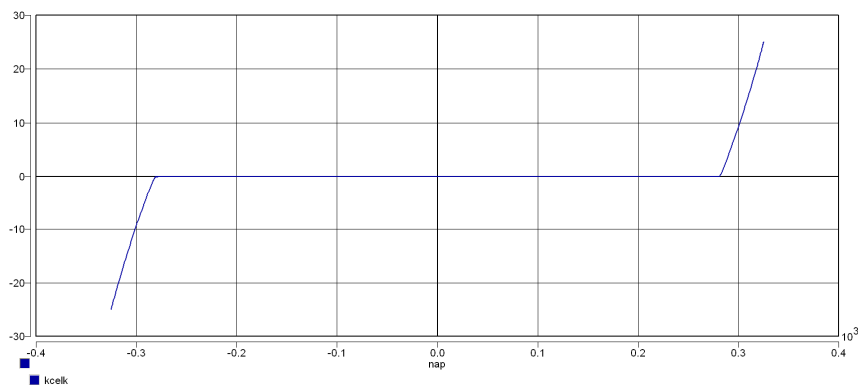


Figure 4 - Voltage-dependent current waveform

This created voltage-dependent current function is assigned to a current source. Actual current magnitude corresponds to the actual voltage in the connection point of the current source. In the cases, where the voltage is lower at input terminal of current source, the magnitude of consumed current is also lower.

• SIMULATED WAVEFORMS

In Fig. 5, there are shown two waveforms of non-harmonic currents that are created as an example in DYNAST program. The first current waveform corresponds to a device with one-phase rectifier and smoothing capacitor. These currents are consumed by TVs, PCs assemblies, monitors, DVDs and others. The second current waveform is typical for devices with six-pulse rectifier and smoothing capacitor. The corresponding currents consume for example frequency converters for three-phase motors of variable units.



Figure 5 – Non-harmonic current waveforms for devices containing a) one-phase rectifier and smoothing capacitor, b) six-pulse rectifier and smoothing capacitor

Curves created in DYNAST program are shown in Fig. 6. The magnitude of x A is chosen for the first simulated non-linear load and y A for the second one. Their magnitudes correspond to the connection of several appliances with the same consumed current from one phase. It may be for example 50 elements of PC assemblies for the first non-harmonic type.

• EXAMPLE OF THE NON-LINEAR CIRCUIT

For evaluating the effects of current harmonics on the supply voltage, it is necessary to assemble the circuit that is composed by voltage source, conductor and variable loads. The loads are set to consume either sinusoidal or harmonics currents. This sample circuit is shown in Fig. 7. It contains above introduced elements, such as source of sinusoidal voltage, power cable, two nonlinear loads and three linear loads.

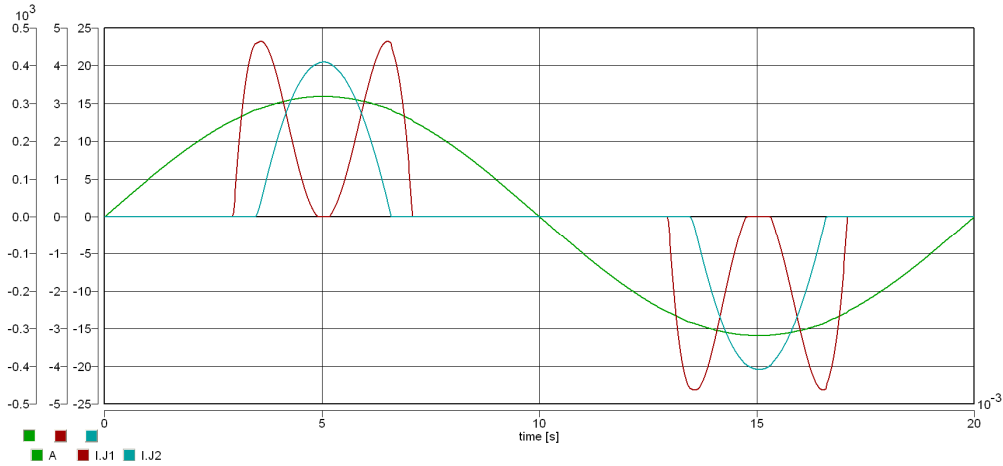


Figure 6 – Simulated non-harmonic waveform

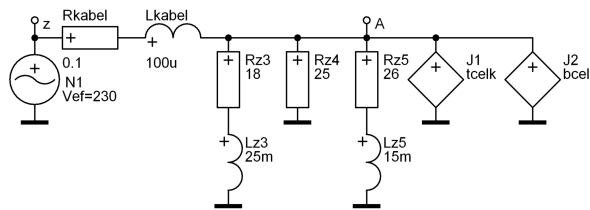
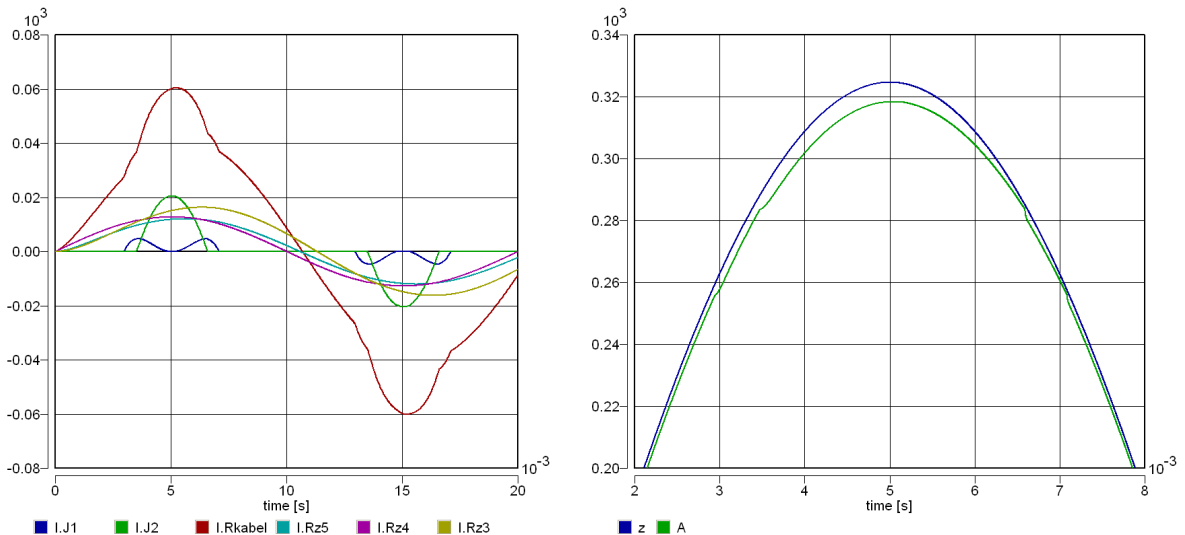


Figure 7 – Linear and nonlinear load circuits

Final current waveforms flowing through the cable are shown in Fig. 8 a). Loading magnitudes are chosen in this simulation so that the influence of harmonics on the total current and voltage in the point of loads connection was visible. Waveforms of voltage source and connection point are shown in Fig. 8 b). There is obvious a small voltage drop on a longitudinal impedance and also harmonics effect. In the times instance with fast changes of flowing current, voltage distortion occurs. It is also visible, that the voltage at the connection point is slightly phase shifted (cable inductance is chosen negligible for no effect on voltage phase shift).



a) b)
Figure 8 – a) load currents, b) voltage distortion in the connection point of nonlinear load

• CONCLUSIONS

Development of nonlinear load models is very complicate issue. It is needed to utilize several programs for ensuring the best current waveforms of harmonics. DYNAST program enables to make these simulations and also identifies effects of harmonics on the supply voltage and total current. Intensive creation of non-harmonic currents is a huge disadvantage. Furthermore, subsequent identification of this current dependence on supply voltage by means of mathematical functions is also very inconvenient.

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