ELECTRICAL HARMONICS MODELING OF OFFICE EQUIPMENTS USING MATLAB AND SIMULINK

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ABSTRACT
Harmonic current pollution is a one of the major power quality problem in electrical power systems. In office buildings one of the main harmonic sources is a large numbers of computer loads. Especially, personal computers apply harmonic distortions to their power supply systems. In this study, harmonics models of equipments, a MATLAB® code and single-phase Simulink simulation models are developed for office equipments in order to analysis harmonic activity in neutral conductor.

Keywords: *Harmonics, Harmonic activity, Computer loads, Modeling, Office equipments, MATLAB, Simulink.*

1. INTRODUCTION
Harmonic producing equipments are found in varied locations from offices to manufacturing plants and they are becoming inevitable in daily life. Various harmonic producing equipments are:

- Personal computers
- Electronic lighting ballasts
- Variable and adjustable speed drives
- Industrial process controls
- Electronic test equipment
- Solid state controls
- UPS systems
- Medical equipments
- Electronic household appliances.

Harmonic currents generated by office equipments increase power system heat losses and the power bills of end users. Generally harmonic problems in office buildings are caused by nonlinear loads causing harmonic current injection. The injected current is propagated to all distribution circuits and leads to harmonic voltage distortion on the system [1]-[2]. Harmonic currents can cause such problems as [3]-[4]:

- Overheating or derating of transformer
- Overloading neutral conductors
- Excessive heating of wiring and connections
- Damaging of capacitor banks
- Resonance
- Malfunction of electronic equipment
- Communication interference
- Distorted supply voltage
- Increased power losses
- Logic faults in digital devices
- Errors in power metering
- Inadvertent thermal tripping of relays, circuit breakers and protective devices.

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The most commonly used measure of the quality of a periodic waveform is the *Total Harmonic Distortion* (*THD*). Current distortion factor is described as follows:

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \qquad (1)$$

where I_1 is the fundamental component of the periodic current waveform and the index "*h*" indicate the order of the harmonic component. For applications and practical calculations 41st or 63rd order in some cases is quite enough. Other index such as *Telephone Interference Factor* (*TIF*) is used to measure telephone interference. The K-factor indices are used to describe the impact of harmonics on losses and are useful in derating equipment such as transformers [5]. IEC recommends limits of harmonic currents for equipment input current is up to and including 16 A per phase in standard 61000-3-2 [6].

Harmonic analysis is a primary matter of power quality assessment. With the widespread use of power electronics equipment and nonlinear loads in industrial, residential and commercial office buildings, the modeling of harmonic sources has become an essential part of harmonic analysis. This paper focuses on modeling of office equipments such as PC, notebook computer, laser and inkjet printers, ups, fax machine and scanner with nonlinear voltage-current characteristics.

2. NONLINEAR MODELING

Solving a circuit, which contains more than one nonlinear element, with common analytic methods, is not possible. If there is a single nonlinear element in a linear network, construction of a load line permits a simple graphical solution. Circuits involving nonlinear elements can be solved in various ways depending on the nature of the problem and the form of the data. Newton-Raphson Iterative Method (*NRIM*) and *Simulink* models are implemented to solve single-phase equivalent circuits [7].

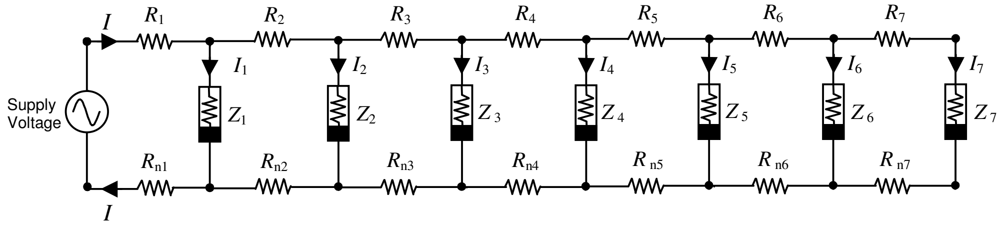

Fig. 1 Single-phase equivalent circuit consisting of nonlinear elements

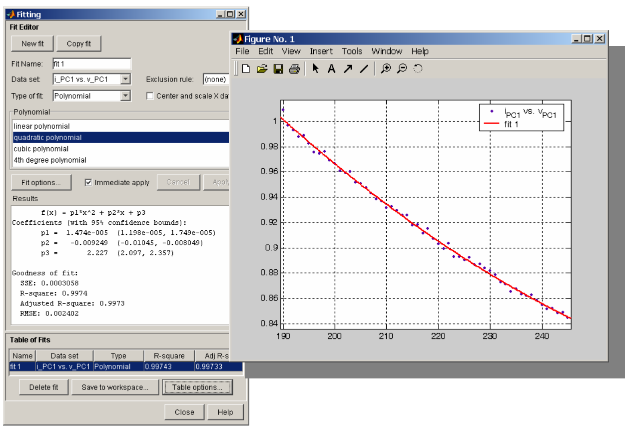

Fig. 2 Nonlinear voltage-current characteristic of a PC

2.1. Nonlinear Voltage-Current Characteristics

The sample equivalent circuit scheme consisting of nonlinear elements is shown in Fig. 1. In order to solve the nonlinear circuit via MATLAB, nonlinear voltage-current characteristics of equipments are obtained using *Curve Fitting* toolbox from real measured data. Polynomial type functions are implemented for the characteristics of all equipments (Fig. 2).

2.2. Newton-Raphson Iterative Method

Since the Newton-Raphson method for solving $F(x) = 0$ which can be a polynomial, or, transcendental equation of one variable is based on the Taylor's series involving the derivatives of $F(x)$, it can be extended to the solution of two-equations $F_1(x,y) = 0$ and $F_2(x,y) = 0$ by application of Taylor's series involving partial derivatives of both F_1 and F_2 with respect to x and y [8]. A MATLAB code has been developed for analyzing nonlinear circuits using *NRIM* with the $V=F(I)$ characteristics. The flowchart of the generated code is shown in Fig. 3.

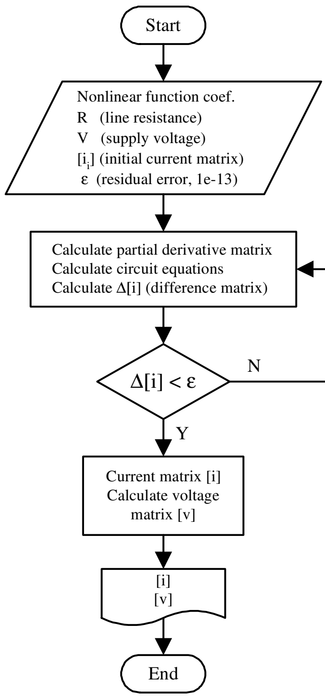

Fig. 3 Flowchart of the MATLAB code for analyzing nonlinear circuit using *NRIM*.

2.3. Simulink Model

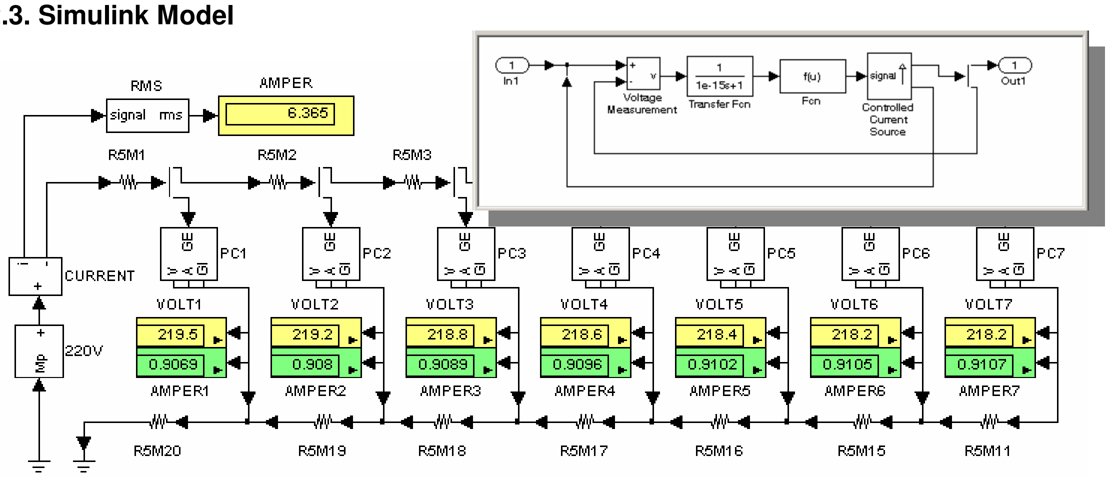

Fig. 4 *Simulink* model of nonlinear circuit consisting of PC loads

Nonlinear modeling in *Simulink* is easier, quicker and more flexible than developing a code. Because of using controlled current source in nonlinear model block, terminal equation must be in form of I=F(V). According the circuit solution of *Simulink* model with nonlinear resistance simulation the voltage and current distribution is obtained. Nonlinear resistance model and voltage-current distribution of a PC are shown in Fig. 4. Currents and voltages of nonlinear resistances calculated from m-file and obtained from *Simulink* for a PC circuit are given in Table 1, for 220 V supply voltage and 5-meter conductor length between equipments.

Table 1 Voltage and current values of nonlinear circuit for 220 V supply voltage

	Voltage (V)						
Model	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	PC_7
NRIM	219.5455	219.1558	218.8309	218.5709	218.3759	218.2458	218.1808
Simulink	219.5454	219.1555	218.8305	218.5705	218.3754	218.2453	218.1802
	Current (A)						
Model	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	PC_7
NRIM	0.9067	0.9077	0.9086	0.9093	0.9099	0.9102	0.9104
Simulink	0.9069	0.9080	0.9089	0.9096	0.9102	0.9105	0.9107

2.4. Harmonic Current Injection Model

Office equipments inspected in this study, because of their switch mode or rectifier power supply, have spiked current waveforms that contain essentially odd harmonics. Consequently, the equipments can be modeled as parallel harmonic current sources with definite magnitude and phase angle as other electronic loads [9]. Harmonic current injection model of PC circuit is shown in Fig. 5. Voltage levels of the harmonic current spectrums varies with the ΔV=1 V.

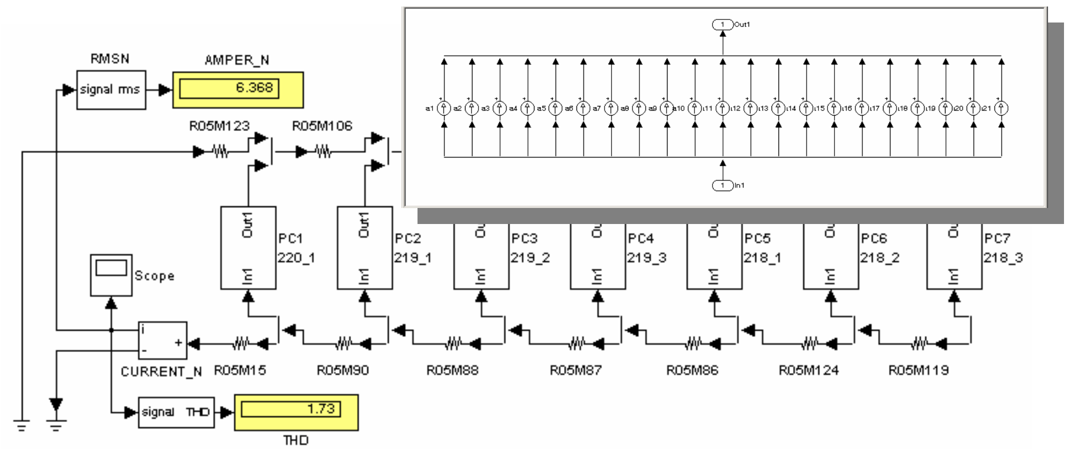

Fig. 5 *Simulink* harmonic current injection model for PC circuit

3. APPLICATION

PC loads are most widespread used equipment in office buildings. Thus, computer loads are the main harmonic sources among the office equipments and in this study modeling the computer loads is major issue for harmonic analysis. In addition to PC load, notebook computer, laser and inkjet printers, ups, fax machine and scanner are also modeled as office equipment. In order to obtain nonlinear characteristics measurements are realized under pure sinusoidal supply voltage with the range of 190-245 V at 50 Hz. As numerical application a single-phase radial system is modeled with PC loads at each node and the other investigated equipments connected at same node with a PC. Applied *Simulink* harmonic current injection model and obtained neutral current, THD_I values are shown in Fig. 6. Distorted neutral current waveform and harmonic spectrum of single-phase circuit acquired from *Fast Fourier Transform* (*FFT*) analysis is given in Fig. 7.

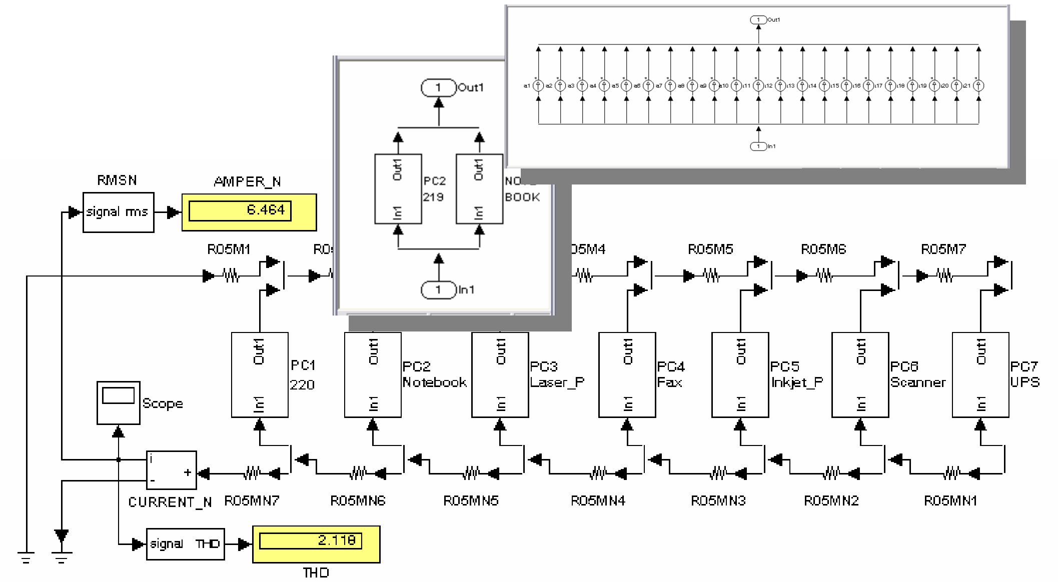

Fig. 6 *Simulink* single-phase harmonic current injection model for office equipments

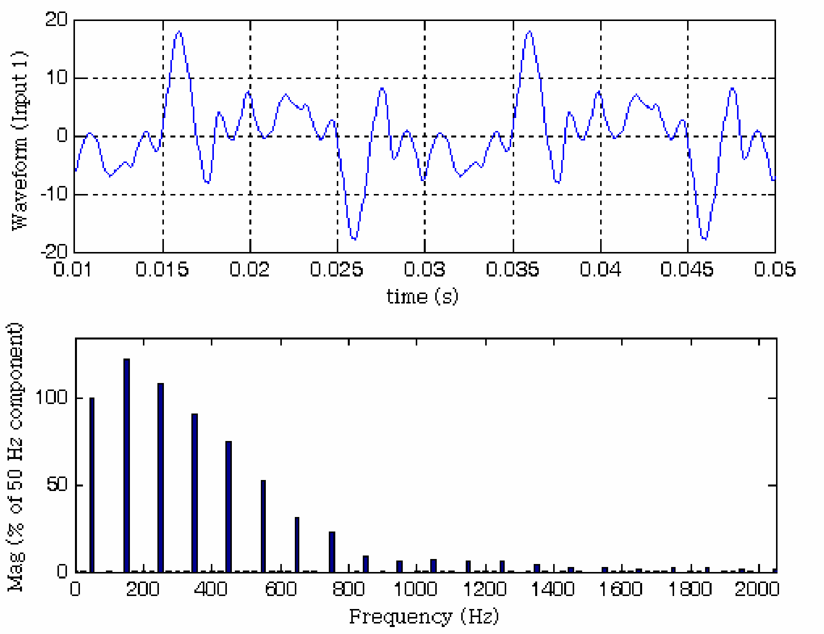

Fig. 7 Neutral current waveform and harmonic spectrum of single-phase installation

4. CONCLUSIONS

In this study harmonics modeling of office equipments is realized for harmonic analysis of modeled systems in *Simulink* with the help of measured real data, voltage-current values and harmonic current spectrums; proposed *Simulink* nonlinear resistance model and harmonics current injection model.

According to the Table 1, voltage and current values obtained from Simulink and calculated using *NRIM* are completely coherent. Therefore nonlinear resistance modeling and solving circuit in *Simulink* is faster, easier and more flexible than developing a code for conventional iterative methods, which is even coded as a MATLAB m-file.

According to Fig. 4 and Fig. 5, line current values acquired from nonlinear circuit (time domain) and harmonic current injection circuit (frequency domain) are very close and better than expected tolerances (<%0.1).

THD value of neutral current observed from Fig. 6 and Fig. 7 is greater than %200, thus some harmonic mitigation options, such as oversizing conductors (especially neutral in three-phase circuits with shared neutrals), applying passive or active harmonic filters, must be carried out and detailed neutral harmonic analysis is needed for circuits mainly consisting of office equipments.

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