Memristive Devices In Three-Phase Systems

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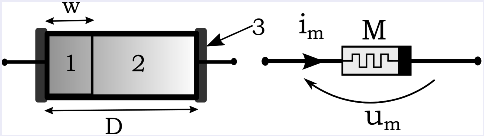
Problem Description

Abstract

- The problem of the usage of memristive elements in three-phase systems is considered.
- The aim of the research was to provide trustworthy simulation results for symmetrical three-phase systems with memristive load.
- The memristors in the system are combined with linear resistors in order to limit the current in the element.
- Linear drift model of the memristor was considered in Matlab simulations (based on Strukov model with Biolek window).
- High nonlinearity of memristor results in deformation of most of the signals in the system.
- A Fast Fourier Transform (FFT) is applied to chosen signals in order to provide a frequency spectrum.
- Total Harmonic Distortion (THD) parameter is calculated.

Introduction

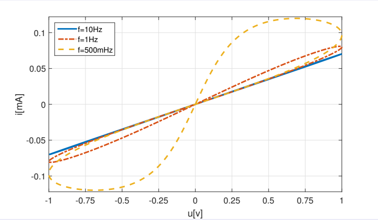
Memristor is the famous fourth basic electric circuit element postulated by Leon Chua in 1971. The discovery of the physical solid-state structures having memristive characteristics by the HP scientists in 2008 has attracted enormous interest in the scientific community.

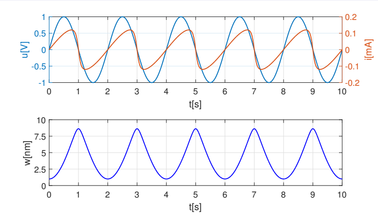


Model of the memristor and its equivalent symbol.
(1-doped region, 2-undoped region, 3-metal contact)

The most crucial property of memristor is the fact, that it can take two significantly different values of resistance in a stable way. This explains, why after 2008 this topic became so popular for scientists specializing in electronics, in particular memories, logic circuits and neuromorphic systems.

Memristor Sinusoidal Response

a) 

b) 

a) - The typical zero-crossing pinched hysteresis loop as the memristor response for the sinusoidal excitation ($U_{\max} = 1\text{V}$).
b) - The voltage and the current in the memristor and the $w(t)$ function vs time t for $f = 0.5\text{Hz}$.

The presented graphs has been achieved using the typical HP memristor parameters:
$\mathcal{R}_{\text{ON}} = 100\ \Omega$, $\mathcal{R}_{\text{OFF}}/\mathcal{R}_{\text{ON}} = 160$, $\mu_v = 10^{-10}\ \text{cm}^2\text{s}^{-1}\text{V}^{-1}$, $D = 10\ \text{nm}$, $U_{max} = 1\ \text{V}$.

Linear Ion Drift (Strukov) Model

The model is based on the assumption that oxygen ions drift with the velocity that depends linearly on the electric field (voltage) in the memristor structure. In this model, the voltage-current relation is given by

$$v(t) = \left(R_{\text{on}} x(t) + R_{\text{off}} (1 - x(t))\right) i(t), \qquad (1)$$

where the internal variable $x(t)$ denotes the relative width of the low-resistance region.

The dynamics of the element is defined by the following formula:

$$\frac{\mathrm{d}x(t)}{\mathrm{d}t} = k R_{\text{on}} i(t), \quad x \in [0, 1]. \qquad (2)$$

To make sure that $x \in [0, 1]$ one can multiply the right hand side of (2) by the *ideal rectangular window function* defined as $f(x) = 1$ for $x \in [0, 1]$ and $f(x) = 0$ outside $[0, 1]$.

Memristor Models

Biolek Window Function

The linear model does not describe all the physical phenomena in the memristor structure.
One of the modifications is to use a different window function $f(x,i)$ to slow down the dynamics when x is close to the border of the interval $[0,1]$. In the presentation we use the very popular window proposed by prof. Biolek.

$$f(x,i) = 1 - (x - \mathbb{1}(-i))^p \,, \tag{3}$$

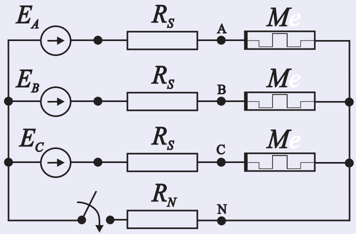
where p is an even integer, and the unit step function $\mathbb{1}(\cdot)$ is defined as $\mathbb{1}(x) = 1$ for $x \geqslant 0$ and $\mathbb{1}(x) = 0$ for $x < 0$. To permit odd values of p authors extend the Biolek window definition as:

$$\frac{\mathrm{d}x(t)}{\mathrm{d}t} = kR_{\mathrm{on}} i(t) \left(1 - |x - \mathbb{1}(-i)|^p\right) . \tag{4}$$

Simulation Software

- All simulations were carried out in Matlab environment.
- Simulation software gives the opportunity to measure and plot all of the signals in three-phase system.
- It is possible to simulate both three-cord and four-cord systems.
- User can also set the specific value of neutral wire resistance, as well as phase wires resistances.

The diagram of the considered circuit

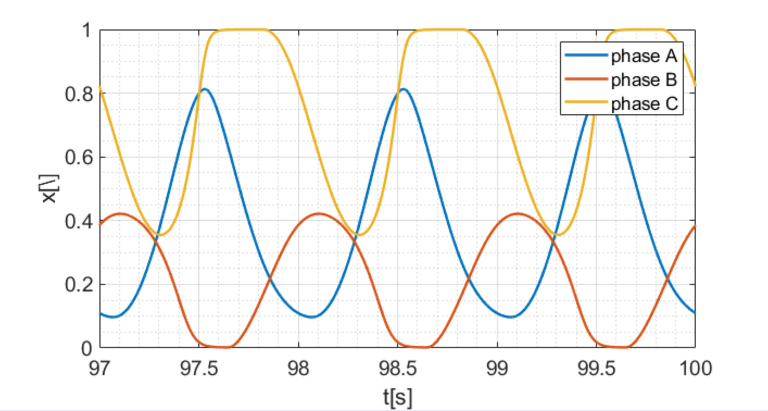


Results

- The main goal of the experiments was to show, how theoretically symmetric three-phase system behaves in terms of existing non-linear memristive elements.
- The simulations was made for the input phase voltages with RMS value 4V and linear resistance 1kΩ in series to memristor.
- We focused on experiments made for the three-cord system.
- The frequency of input signals varies from 1Hz to 500Hz.

Results

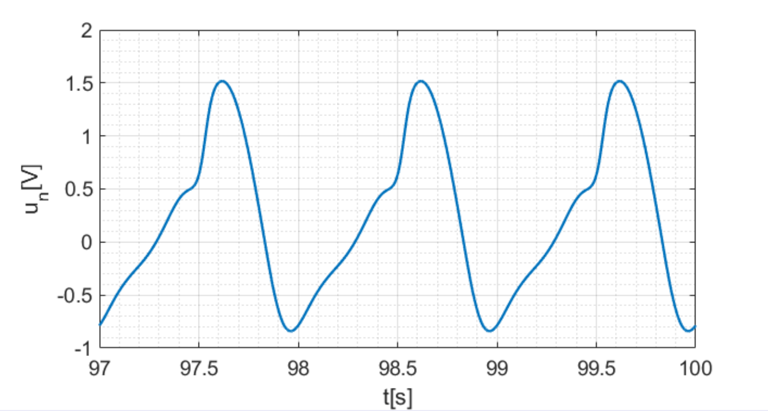
Internal variable x for memristors in phases A, B and C. Three-cord system. Input signal frequency f=1Hz



Shape of the internal variable x impacts on actual value of the resistance of memristor. This causes high non-linearity, which reveals in the shape of neutral point voltage signal.

Results

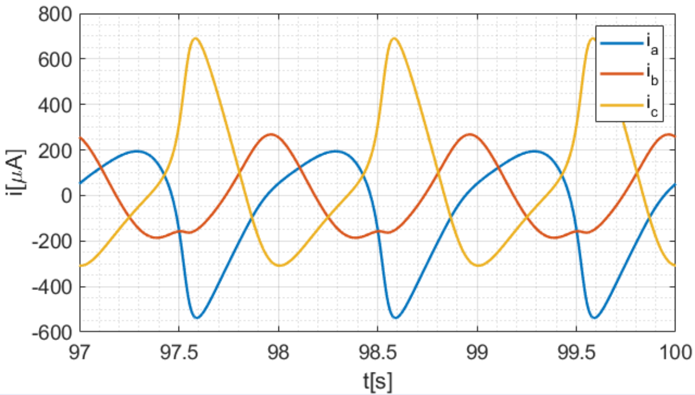
Neutral point voltage. Three-cord system. Input signal frequency f=1Hz



Since neutral point voltage is non-sinusoidal, all other signals in the system are non-sinusoidal.

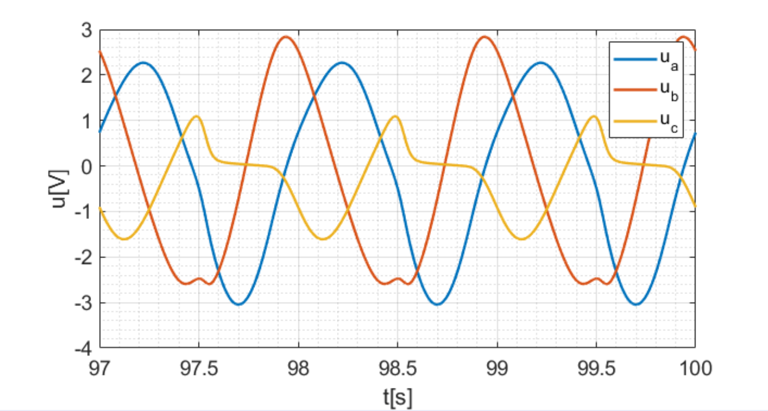
Results

Phase currents. Three-cord system. Input signal frequency f=1Hz



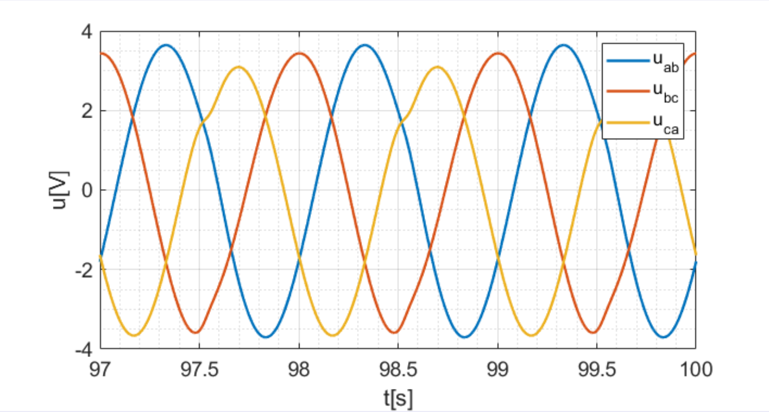
Results

Phase voltages. Three-cord system. Input signal frequency f=1Hz



Results

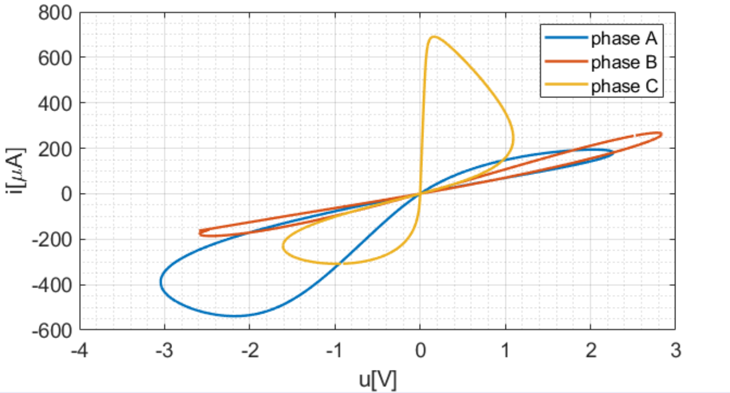
Delta voltages. Three-cord system. Input signal frequency f=1Hz



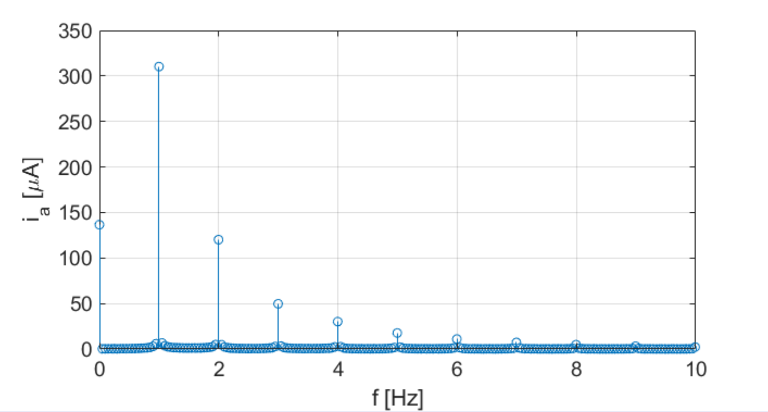
Delta voltages (line voltages) are measured between connection nodes of linear resistor and memristor in each phase. Clearly, they are less deformed than other signals.

Results

Hysteresis loop for phase voltages and currents. Three-cord system. Input signal frequency f=1Hz

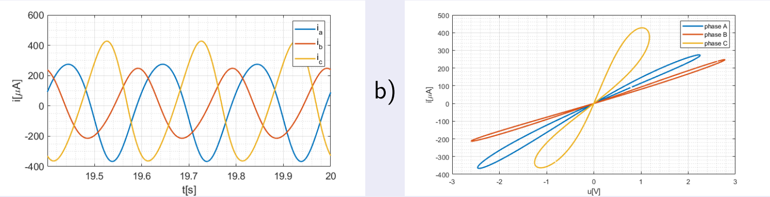


Fast Fourier Transform for i_a. Three-cord system. Input signal frequency f=1Hz



Chosen signals for input signal frequency f=5Hz

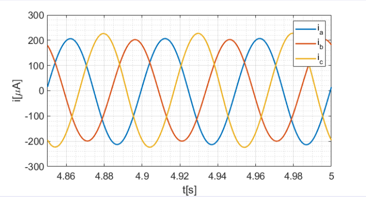
a) b)

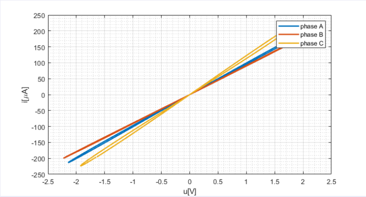


a) - Phase currents. b) - Hysteresis loop for phase voltages and currents.

Results

Chosen signals for input signal frequency f=20Hz

a) 

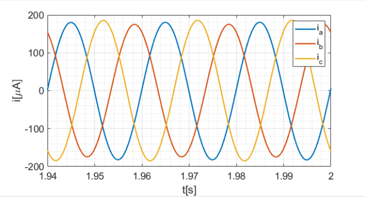
b) 

a) - Phase currents. b) - Hysteresis loop for phase voltages and currents.

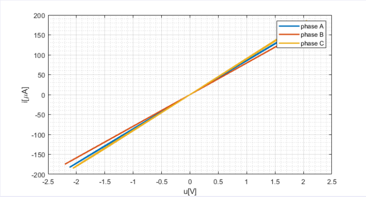
Results

Chosen signals for input signal frequency f=50Hz

a)



b)



a) - Phase currents. b) - Hysteresis loop for phase voltages and currents.

Conclusions

Frequency Observations

1. For lower frequencies high nonlinearity is observed.
2. The higher frequency, the more linear behavior of the memristive element.
3. For frequencies 100Hz and higher, the system behaved like fully linear system.
4. The shape of the pinched hysteresis loop narrows down with increasing the frequency.
5. For frequencies 500Hz and higher it is straight line, so the memristor behaves as regular linear resistor.

Total Harmonic Distortion

$$\mathrm{THD_F} = \frac{1}{I_{\mathrm{a_1}}}\sqrt{\sum_{k=2}^{\infty} I_{\mathrm{a_k}}^2}$$

Basic parameters of i_a versus f

f [Hz]	THD [dB]	THD (lin)	I_a [A] (RMS)	I_am [A] (mean value)
1	-7.1953	0.43675108	$2.49 \cdot 10^{-4}$	$-6.83 \cdot 10^{-5}$
5	-19.4748	0.10623413	$2.25 \cdot 10^{-4}$	$-1.62 \cdot 10^{-5}$
20	-37.2767	0.01368248	$1.46 \cdot 10^{-4}$	$-1.41 \cdot 10^{-6}$
50	-48.0445	0.00396073	$1.27 \cdot 10^{-4}$	$-3.88 \cdot 10^{-7}$
100	-55.8916	0.00160480	$1.17 \cdot 10^{-4}$	$-1.61 \cdot 10^{-7}$
200	-63.7429	0.00064991	$1.09 \cdot 10^{-4}$	$-7.02 \cdot 10^{-8}$
500	-74.0836	0.00019761	$1.02 \cdot 10^{-4}$	$-2.76 \cdot 10^{-8}$

Future Work

- Simulation results for four-cord systems will be published.
- The measurements on real three-phase systems with memristive load is planned.
- In order to achieve this, the authors have to create a precise phase-shifting module, corresponding to existing measuring system.

Thank You
For Your Attention