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Research Paper

Study of transitory phenomena at connecting the capacitive loads to an AC power source

Titu Niculescu, Marius Marcu, Florin-Gabriel Popescu*

Department of Control Engineering, Computers, Electrical Engineering and Power Engineering, University of Petrosani
**Corresponding author E-mail: floringabriel82@yahoo.com*

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Abstract

This paper presents a new and a modern method for study the inductive-capacitive circuits which are connected to an AC power source, using modern methods based on digital technology and software used in engineering applications. The capacitive circuits which are switched on an AC power source at the initial moment are presented below. We can determine the capacitor current variation forms, the capacitor voltage in a transient regime by using virtual mediums, in two different regimes: the oscillating regime and the-periodic regime. Each presented case contains an analytical presentation of the phenomenon, but it also contains the diagrams of current and voltage capacitors. The diagrams were obtained by two methods, which use MATLAB package. These diagrams are compared with experimental measurements obtained with a data-acquisition system produced by National Instruments using LABVIEW software.

Keywords: *Capacitive Circuit; Data's Acquisition; Diagrams; Differential Equation; Labview; Simulation Model; Simulink.*

1. Introduction

We can consider a RLC series circuit with concentrated parameters, which will be connected to an AC power source. We can meet this situation in practice, in case we want to connect to AC power source electrical equipment which includes capacitors. In this case can occur overvoltage or over currents during transient regime, which can cause problems system sizing. The circuit inductivity forms with the capacitors an oscillating circuit (Fig.1).

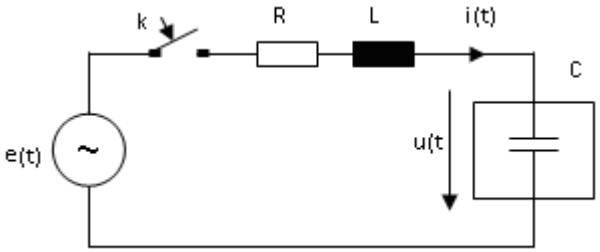


Fig. 1: Capacitor Connecting to an AC Voltage Source

The differential equation for transitory phenomena is presented below, where "u (t)" is the capacitor voltage.

$$LC\frac{d^2u(t)}{dt^2}+RC\frac{du(t)}{dt}+u(t)=U_m\sin(\omega t+\psi) \quad (1)$$

Where Ψ is the initial phase of voltage when the circuit was connected.

2. Theoretical considerations

2.1. The oscillatory regime

This event is known in the scientific literature as an oscillating regime. If we consider the R resistance of a circuit very small, the Laplace's method applied to this circuit conducts to the following solution [4]:

$$u(t) = \frac{U_m \sin(\omega t + \psi - \phi_1)}{C\omega\sqrt{R^2 + (\frac{1}{\omega C} - L\omega)^2}} + \frac{DU_m e^{-\delta t}}{2LC\omega_e^2}\sin(\omega_e t - \gamma) \quad (2)$$

Where δ is a dumping factor?

$$\delta = \frac{R}{2L} \quad (3)$$

And ω_0 is the resonance angular frequency of the circuit:

$$\omega_0 = \frac{1}{\sqrt{LC}} \quad (4)$$

We also used the following notations:

$$\omega_e = \sqrt{\omega_0^2 - \delta^2} \quad (5)$$

$$D = \sqrt{A^2 + B^2 - 2AB\cos(\beta - \alpha)} \quad (6)$$

$$tg\,\gamma = \frac{A\sin\alpha - B\sin\beta}{A\cos\alpha - B\cos\beta} \quad (7)$$

$$\alpha = \phi_3 + \psi\,; \qquad \beta = \phi_2 - \psi \quad (8)$$

$$\phi_1 = arctg\,\frac{2\omega\delta}{\omega_0^2 - \omega^2} \quad (9)$$

$$\phi_2 = arctg\,\frac{\delta}{\omega_e - \omega} \quad (10)$$

$$\phi_3 = arctg\,\frac{\delta}{\omega_e + \omega} \quad (11)$$

$$A = \frac{1}{\sqrt{(1 + \frac{\omega}{\omega_e})^2 + (\frac{\delta}{\omega_e})^2}} \quad (12)$$

$$B = \frac{1}{\sqrt{(1 - \frac{\omega}{\omega_e})^2 + (\frac{\delta}{\omega_e})^2}} \quad (13)$$

It is noticed that the capacitors' voltage at its terminals contain a periodic component and a damped oscillatory component, which is canceled after a while from the connection moment. The solution for capacitor current results from expression (2) [4]:

$$i = I_m\cos(\omega t + \psi - \phi_1) + \frac{DU_m e^{-\delta t}}{2\omega_e L}\cdot\left[\cos(\omega_e t - \gamma) - \frac{\delta}{\omega_e}\sin(\omega_e t - \gamma)\right] \quad (14)$$

Where:

$$I_m = \frac{U_m}{\sqrt{R^2 + (\frac{1}{\omega C} - \omega L)^2}} \tag{15}$$

The current circuit contains also a periodic component and a damped oscillatory component, which disappears after a while from the connection moment.

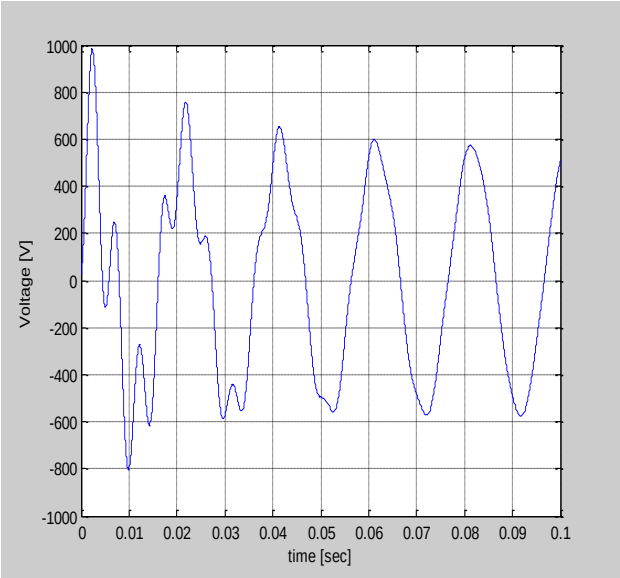


Fig. 2: Capacitor Voltage Diagram in the Oscillatory Regime

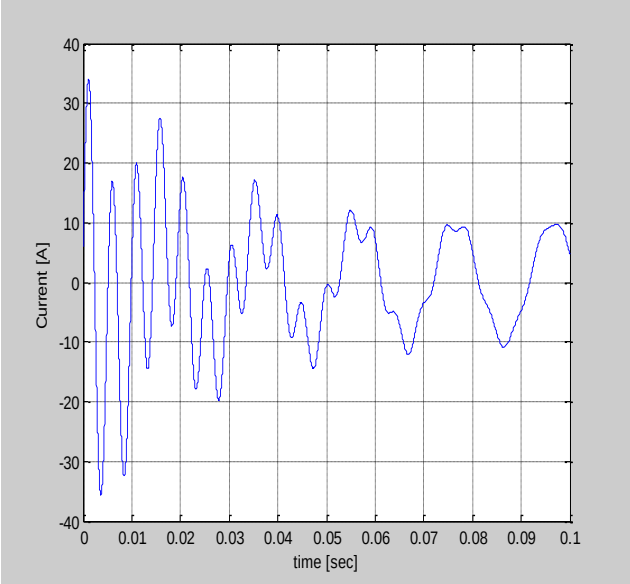


Fig. 3: Capacitor Current Diagram in the Oscillatory Regime

Diagrams from Fig.2 and Fig.3 are based on analytical expressions (2) and (14), and are plotted for the following value of electric circuit parameters, in MATLAB space by programing:

U_{ef} = 380 [V]; R= 1 [Ω]; L= 12 [mH]; C= 50 [μF]; F=50 [Hz]; Ψ = 1.1[rad].

2.2. The aperiodic regime

We consider that the resistance R is very big ($\delta > \omega_0$). This situation is known as an aperiodic regime [4]. In this case:

$$\omega_e = \sqrt{\delta^2 - \omega_0^2} \tag{16}$$

The original solution for equation (1) in this situation is [3]:

$$u(t) = \frac{U_m \sin(\omega t + \psi - \phi_1)}{C\omega\sqrt{R^2 + (\frac{1}{C\omega} - L\omega)^2}} + \frac{U_m}{2} \cdot \frac{\omega_0^2}{\omega_e} \cdot \left[\frac{e^{-(\delta - \omega_e)t} \sin(\phi_2 - \psi)}{\sqrt{(\omega_e - \delta)^2 + \omega^2}} - \frac{e^{-(\delta + \omega_e)t} \sin(\phi_3 - \psi)}{\sqrt{(\omega_e + \delta)^2 + \omega^2}} \right] \tag{17}$$

In the expression that gives the instantaneous voltage in this regime, have made notations:

$$\phi_1 = arctg \frac{2\delta\omega}{\omega_0^2 - \omega^2} \tag{18}$$

$$\phi_2 = arctg \frac{\omega}{\delta - \omega_e} \tag{19}$$

$$\phi_3 = arctg \frac{\omega}{\omega_e + \delta} \tag{20}$$

Based on expression (17) is obtained the current expression in the aperiodic regime [4]:

$$i = I_m \cos(\omega t + \psi - \phi_1) + \frac{U_m}{2\omega_e L}[\frac{(\delta + \omega_e)\sin(\phi_3 - \psi)\cdot e^{-(\delta-\omega_e)t}}{\sqrt{(\omega_e + \delta)^2 + \omega^2}} - -\frac{(\delta - \omega_e)\sin(\phi_2 - \psi)\cdot e^{-(\delta-\omega_e)t}}{\sqrt{(\omega_e - \delta)^2 + \omega^2}}] \quad (21)$$

Where I_m is given by (15). Expressions (17) and (21) give the MATLAB diagrams in the aperiodic regime from Fig.4 and Fig.5. These diagrams were obtained for the following value of input parameters:
U_{ef} = 240 [V]; R= 15 [Ω]; L= 12 [mH]; C= 50 [μF]; F=50 [Hz]; Ψ =1.1 [rad].

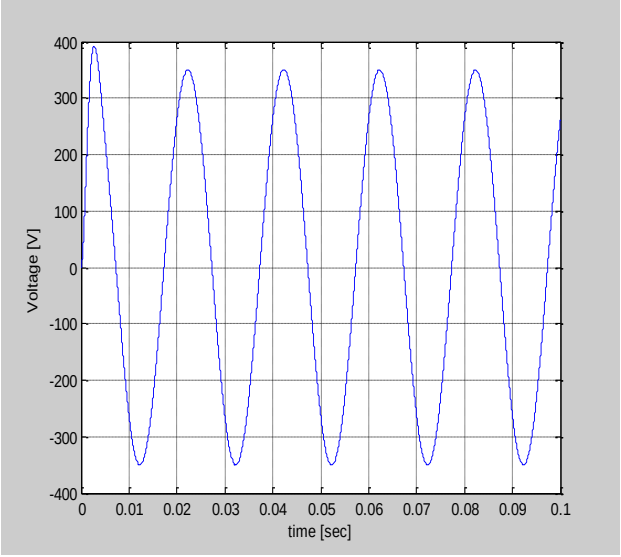


Fig. 4: Capacitor Voltage Diagram in the A-Periodic Regime

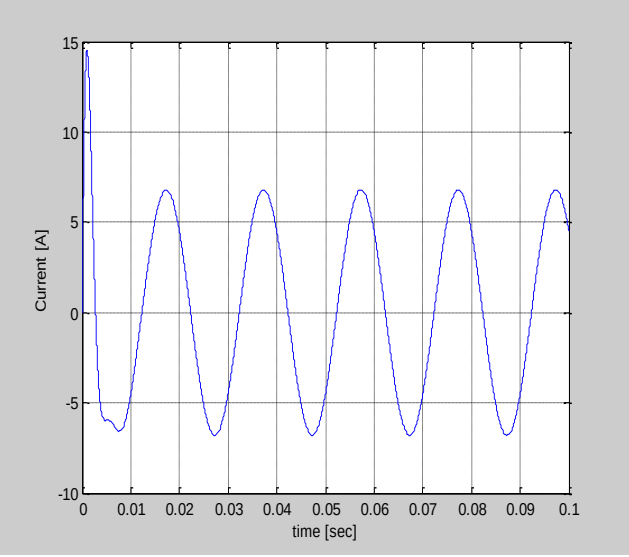


Fig. 5: Circuit Current Diagram in the A-Periodic Regime

3. Simulink model of capacitive circuit

The SIMULINK model for capacitor current in the-periodic regime was made in agreement with the mathematics form (1). This model allows the generation the capacitor current and voltage diagrams for all regimes (Fig.6).

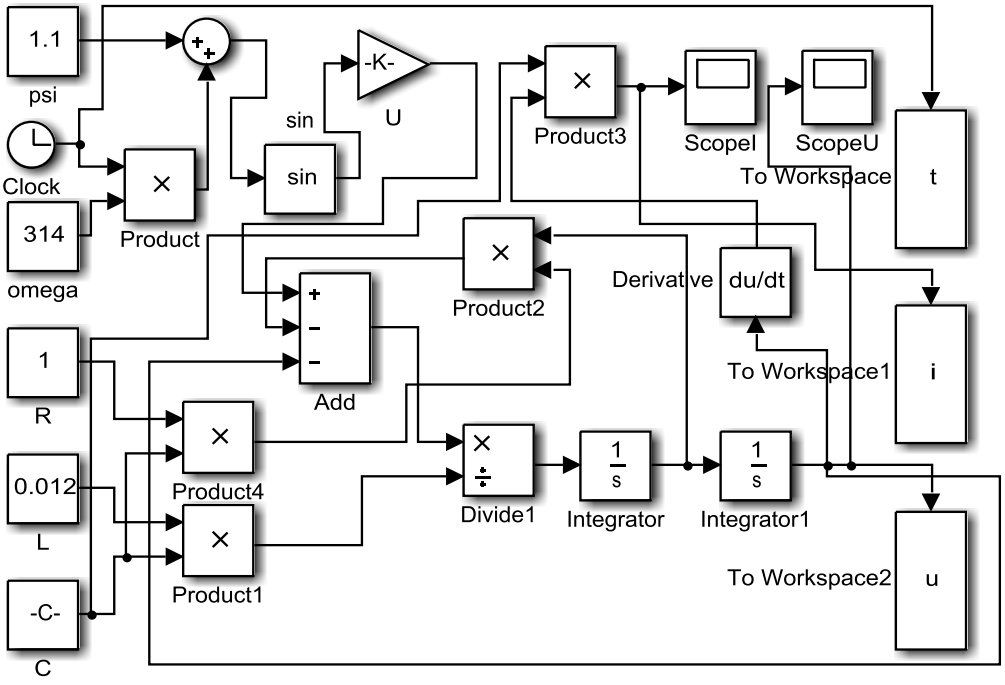


Fig. 6: Simulation Model for Current and Voltage Capacitor

The model integrates the differential equation (1) and allows tracing the forms of voltage and current variation regardless of operating regime. It was conceived to allow plotting the current and voltage diagrams for any value of

circuit's parameters, which are input parameters for this model. The output forms of the model can be plotted by scopes or can be saved in workspace for further processing.
For the set of values corresponding to the oscillating regime are obtained the diagrams from Fig.7 and Fig.8:

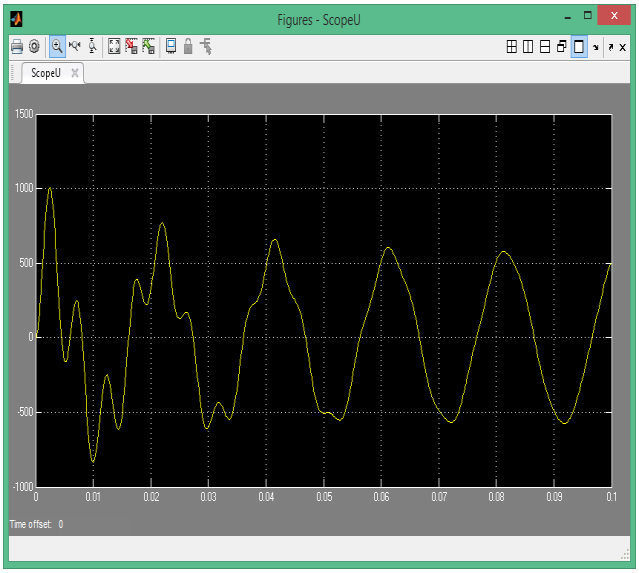


Fig. 7: Capacitor Voltage Diagram in the Oscillating Regime

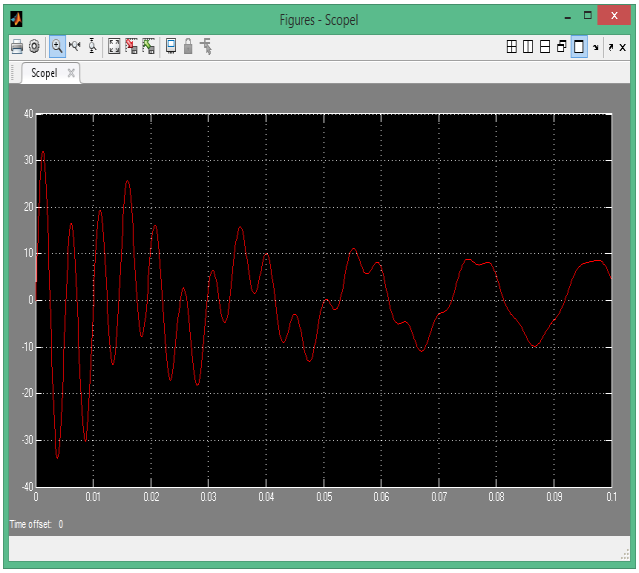


Fig. 8: Capacitor Current Diagram in the Oscillating Regime

The flowcharts of Fig. 7 and Fig. 8 were plotted for the same values of electrical parameters that the diagrams from Fig.2 and Fig.3. It can be seen that the two sets of diagrams render identical dependences.
If in numerical simulation from Fig.6 are given parameters which correspond to the a-periodic regime, it can obtain the variation forms specific for this regime:

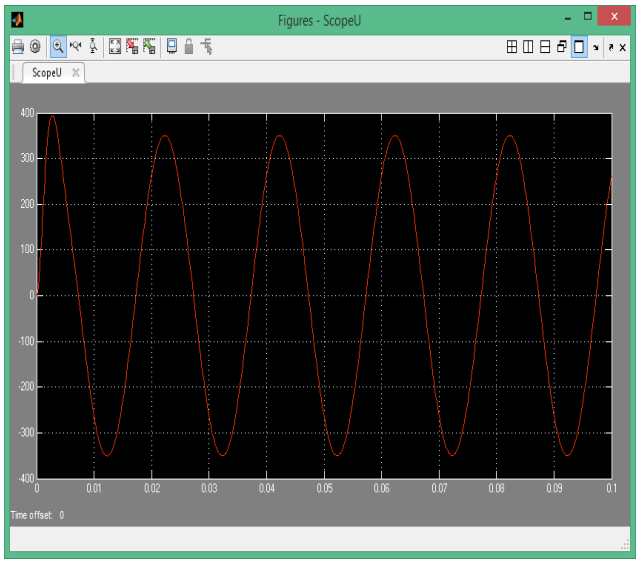


Fig. 9: Capacitor Voltage Diagram in the A-Periodic Regime

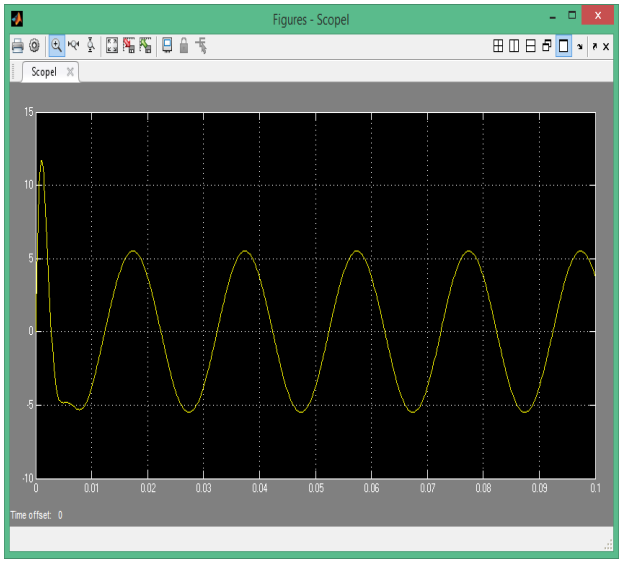


Fig. 10: Capacitor Current Diagram in the A-Periodic Regime

In Fig.9 was plotted the capacitor voltage diagram in the-periodic regime. It can see a voltage peak at the started of transitory regime and a while depreciation of these peaks. The diagram from Fig.10 shows a over current peak in the beginning of process in the-periodic regime.

4. Experimental determination of the variation forms for voltage and current

For experimental confirmation of these results, we used a data-acquisition system produced by the company National Instruments, NI USB-type 6003. Graphical environment used is the Labview software. The schema of the data acquisition in Labview is shown in Fig. 11, and the electrical scheme used is that of Fig. 12. Inductive-capacitive circuit is connected to the mains voltage via a contactor alternative C, and input voltage levels in DAQ are obtained by resistive dividers. How to measure the differential is chosen.

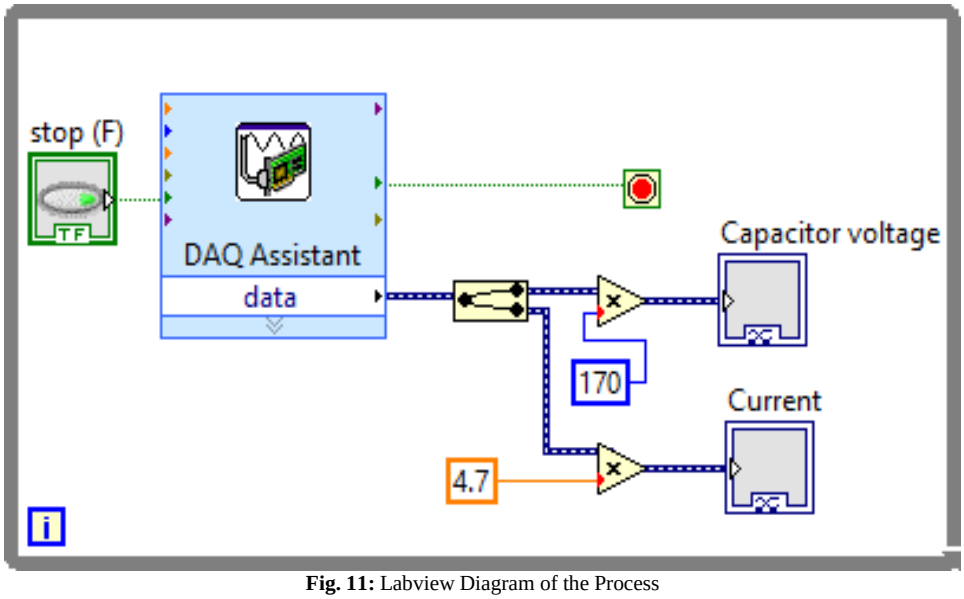


Fig. 11: Labview Diagram of the Process

Numeric constants included in Fig. 11 are correlated with the values of the resistors R0, i0, R R1 and Ri1 forming the two voltage dividers. To eliminate the risk to connect directly the phase voltage alternatives to the DAQ software have symmetrical voltage dividers used, the analog input of the measuring system is connected in parallel with the median flowing. For the protection of the analog inputs to the eventual DAQ inductors, diodes were used Zenner DZ.

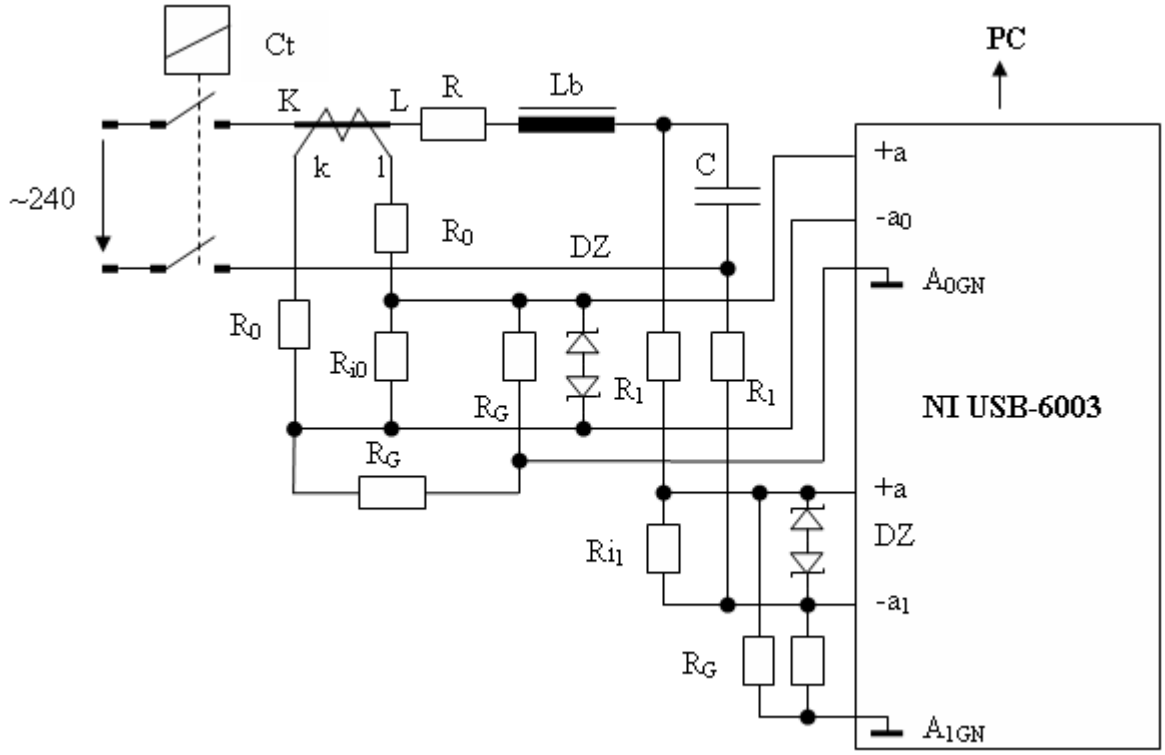


Fig. 12: Wiring Diagram of Installation of Measurement

The following measurements were obtained the following diagrams' variation of the voltage at the terminals of the capacitor and the current in the circuit.

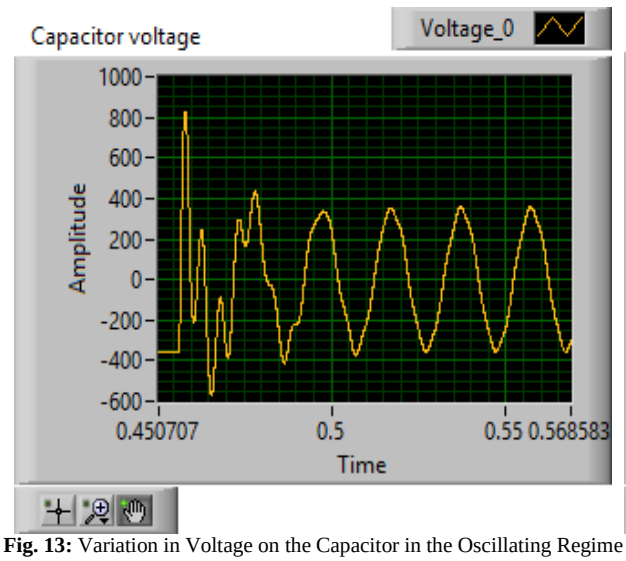


Fig. 13: Variation in Voltage on the Capacitor in the Oscillating Regime

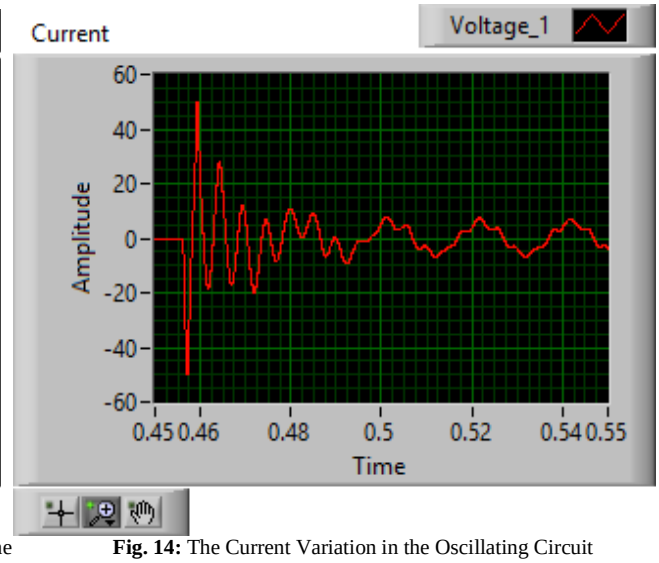


Fig. 14: The Current Variation in the Oscillating Circuit

For oscillatory regime with the parameter values for which the circuit has been obtained the previous diagrams (Fig. 2, Fig. 3, Fig. 7, Fig. 8), resulting in Fig. 13 and Fig. 14 diagrams.
For the corresponding values for aperiodic arrangements (it increased the value of the resistance of the circuit 15 Ω), diagrams have been obtained:

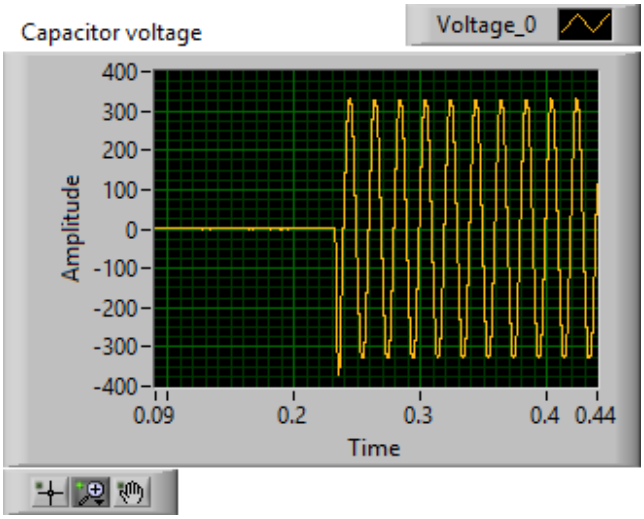


Fig. 15: Variation in Voltage on the Capacitor in Aperiodic

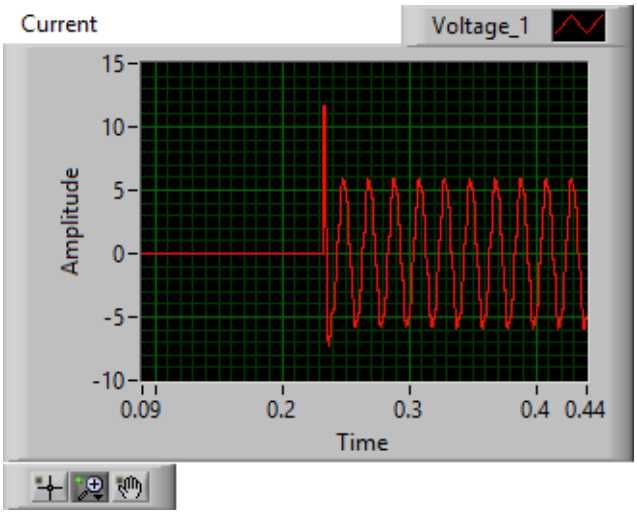


Fig. 16: The Current Variation in the Aperiodic Circuit Arrangements

5. Conclusion

All three methods presented for study the transitory phenomena which appear at a connecting capacitor banks to an AC power source, lead to the same conclusions. The variation forms of electrical parameters are identical in the first two cases. In the last situation, the results are very similar with the theoretical approach, which confirms that these methods are correct.
The first case presented, which is based on MATLAB programming space, is more complicated, because it involves solving the differential equation (1), finding solutions in every regime and creating programs for each situation: two programs for voltage and current in the oscillating mode and two programs for these parameters in the aperiodic regime.
The second method presented simplifies this problem because it does not require knowledge of mathematics needed to solve equation (1). Based on this equation was developed a Simulink model that integrates a second-order differential equation. This model is unique because it leads to getting forms for voltage and current variation in both regimes, depending on the values of circuit parameters.
The experimental method is based on the acquisition of data leads to very closely resemble the diagrams obtained a theoretical way.
The most dangerous regime is the oscillating regime, and this is the most common regime which we can in practice the power-supply voltage of AC electric motors what includes the starting capacitor. The regime most frequently is the oscillating, considering that the resistance of the connecting wires is small. In this case, oscillating overvoltage may occur that need to be taken into account when sizing the systems. The value of these voltages depends on the connecting

moment, which is the initial phase of the AC voltage. The design and sizing of these circuits must take into account the surge peaks that occur immediately after signing in and, which may endanger the internal insulation of the equipment. Overcurrent peaks in oscillating mode can lead to the prosecution of any protective relays on the circuit.
The connecting of capacitor's banks as a power source, at low voltage, can be made directly without dumping resistance (oscillatory regime). The frequency of current oscillations at connecting is approximate one kHz. This can take place at low voltage for capacitor banks to 25 kVAr.
It is important that the electric charge on the capacitor which is connected to be initially zero. Otherwise high value over current may occur in the after connecting moment.
We have to mention that these developed models can be used to generate explicit dependence for every real value of the circuit parameters.

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