Annals of the University of Craiova, Electrical Engineering series, No. 48, Issue 1, 2024; ISSN 1842-4805 eISSN 2971-9852

Simulations and Tests Regarding the Operation of Air Heaters for Industrial Buildings

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***Abstract* - This paper presents a series of simulations for the operation of a reluctance synchronous motor with continuous rotation (RSM), used for air heaters heating industrial buildings. The introduction aims at presenting the domain we analyze. On this occasion, several possibilities for mounting air heaters for industrial buildings are specified. Their operating methods are specified, with emphasis on the case of the reluctance synchronous motors. The mathematical model of these motors, written in the two axes theory, is detailed below; the significance of the quantities used is specified. With the help of this model, a Matlab program was carried out, for simulating the dynamic regimes, specific to the driving motor of air heaters. The paper presents a series of simulations, obtained by means of this program. The simulations regard a fault situation, materialized in an accidental decrease of the motor supply voltage. The graphs obtained refer to the main electrical, mechanical and magnetic quantities specific to the motor. They are accompanied by several relevant conclusions that emphasize the behavior of the motor in the analyzed dynamic regime. The following aspects are regarded: the evolution of the operation point, the influence on the phase current, the influence on the magnetization flux and the rotor speed. These characteristics were experimentally confirmed (indirectly) by emphasizing, in steady state, the evolution of the phase current for the initial and fault cases. The paper ends with references, organized in the order of citations.**

Cuvinte cheie: *cladiri industriale, aeroterme, motor sincron cu reluctanta variabila, model matematic, simulari, incercari.*

Keywords: *industrial buildings, air heaters, reluctance synchronous motor, mathematical model, simulations, tests.*

I. INTRODUCTION

The problem of disturbances that affect the operation of driving systems endowed with special motors is widely developed in the specialized literature.

Thus, electromagnetic compatibility issues are approached in conferences dedicated to these issues [1], [2], [3], energy quality issues are presented in specialized journals [4], [5], [6] or ways of measuring disturbances generated by different sources are emphasized [7], [8], [9].

This paper aims at analyzing a voltage disturbance situation for the operation of a RSM driving an air heater used in an industrial building.

Air heater is a high-performance heating device, which can heat an industrial space, in a relatively short time. It can be controlled by using a thermostat.

Air heaters can be mounted:

- on a side wall (Fig. 1);

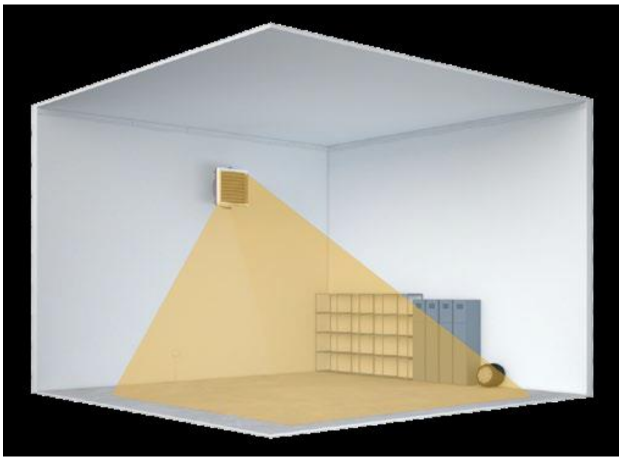


Fig. 1. Wall mounting [10].

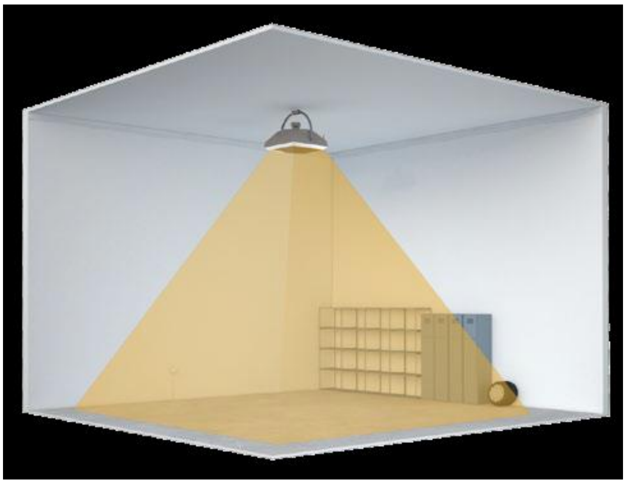


Fig. 2. Ceiling mounting [10].

- on the ceiling (Fig. 2).

The air heater produces hot air that must be distributed throughout the building space.

The air is drawn in by a fan. It has an optimized profile and the increase in the surface area of the blades ensures silent operation and low operating costs.

The fan is, in its turn, driven by an electric motor. This motor is generally a three-phase one, in case of industrial buildings.

Moreover, in order to avoid sparks and, therefore, possible explosions, alternating current motors are used.

The most recent version of such motors, used in industrial ventilation systems, is the reluctance synchronous one.

A particular operation regime of such motor is proposed for analysis below.

II. MATHEMATICAL MODEL

In order to carry out the simulations, the mathematical model of RSM, detailed in [11], was used.

The model, without considering the saturation, consists in five equations, the last one being the motion one. Their matrix form is presented in (1); this form is easy to implement in a Matlab computation program.

$$\begin{bmatrix} L_d & 0 & L_{md} & 0 & 0 \\ 0 & L_q & 0 & L_{mq} & 0 \\ L_{md} & 0 & L_D & 0 & 0 \\ 0 & L_{mq} & 0 & L_Q & 0 \\ 0 & 0 & 0 & 0 & \frac{J}{p} \end{bmatrix} \cdot \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \\ i_D \\ i_Q \\ \omega \end{bmatrix} = \tag{1}$$

$$= \begin{bmatrix} u_d - R_s i_d + \omega L_q i_q + \omega L_{mq} i_Q \\ u_q - R_s i_q - \omega L_d i_d - \omega L_{md} i_D \\ - R_D i_D \\ - R_Q i_Q \\ \frac{3}{2} p\left(L_d i_d i_q + L_{md} i_D i_q - L_q i_q i_d - L_{mq} i_Q i_d\right) - m_r \end{bmatrix}$$

The notations used have the following meanings:

- u_d, u_q - the stator voltage components in the two axes theory;

- i_d, i_q - the components of the stator current in the two axes theory;

- i_D, i_Q - the components of the rotor current in the two axes theory;

- ω - rotor angular speed;

- R_s - stator resistance;

- R_D, R_Q - the rotor resistance components in the two axes theory;

- L_d, L_q - the stator inductance components in the two axes theory;

- L_{md}, L_{mq} - the components of the magnetization inductance in the two axes theory;

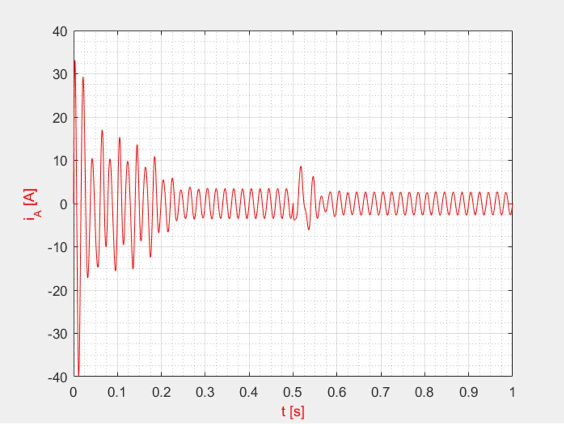
- p - the number of pole pairs;

- J - the inertia moment;

- m_r - the resistant torque.

III. SIMULATIONS

A Matlab program was carried out by means of the mathematical model presented above, for analyzing the operation of the RSM in a dynamic state. Thus, two operation situations, affected by external disturbances, have been simulated (Fig. 3); these disturbances were applied after an interval of 0.5 s from the moment of starting by direct coupling at the electrical network.



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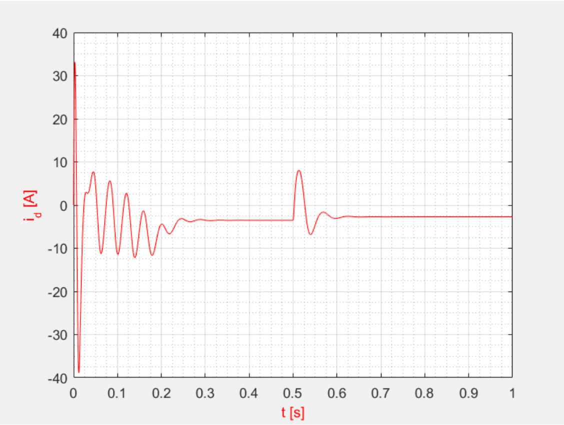

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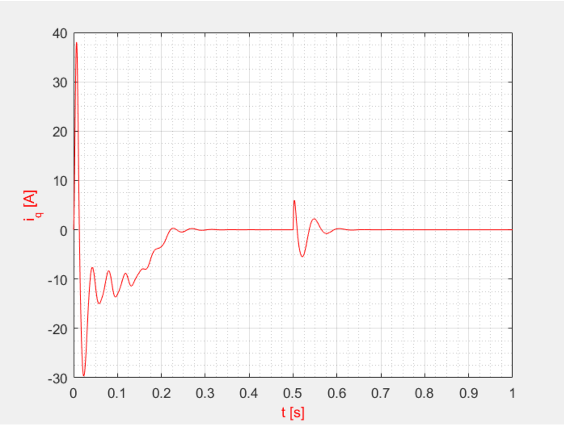

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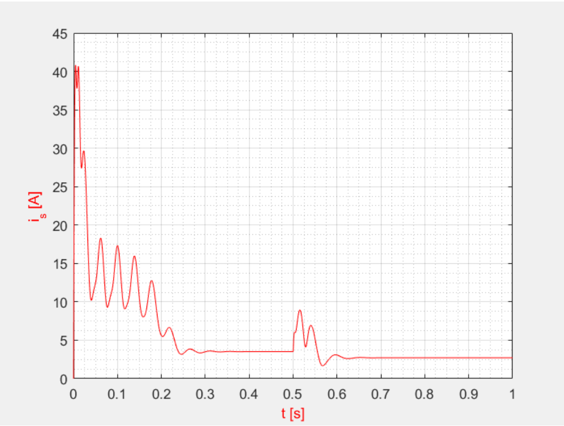

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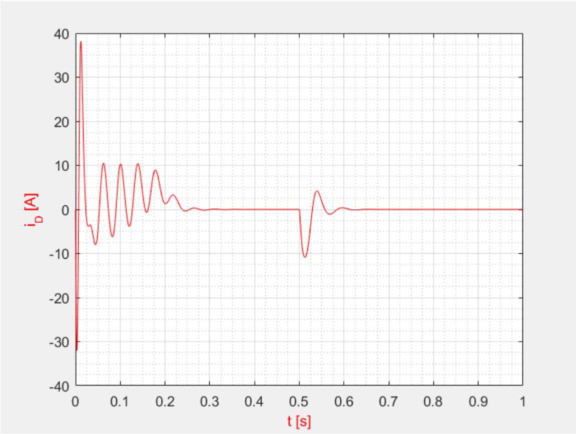
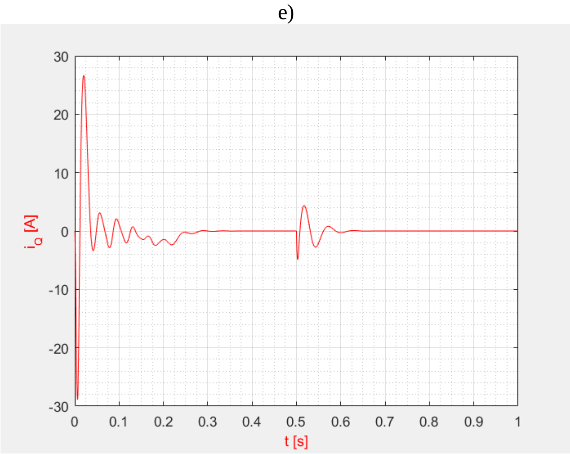

i_D [A]
t [s]
e)


i_q [A]
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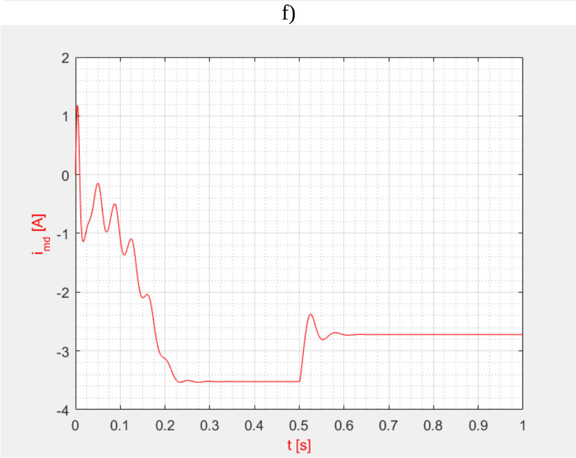
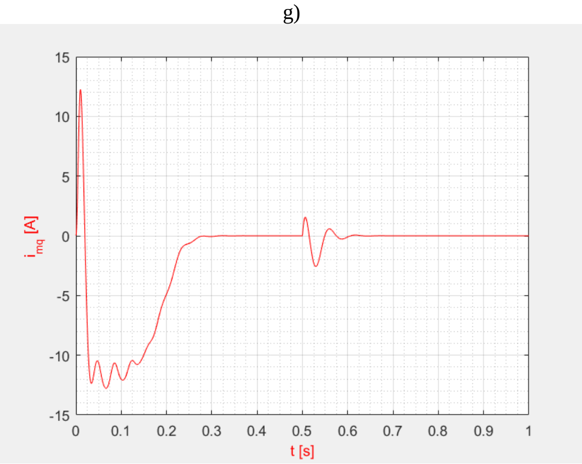

i_md [A]
t [s]
g)


i_mq [A]
t [s]
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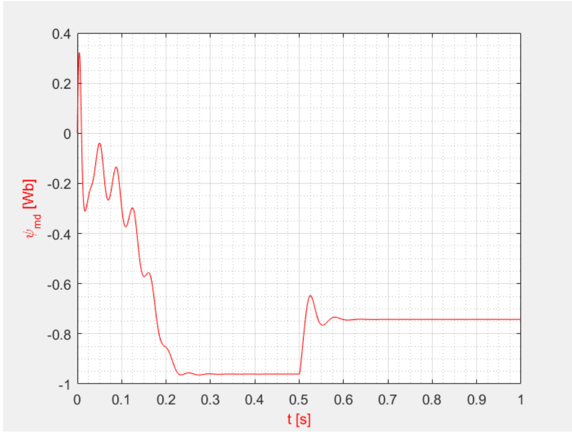
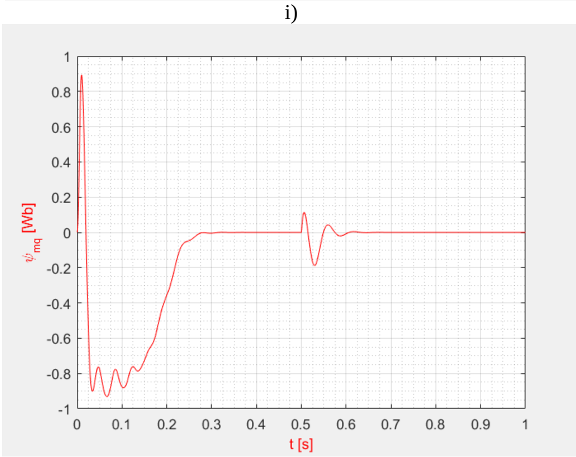

ψ_md [Wb]
t [s]
i)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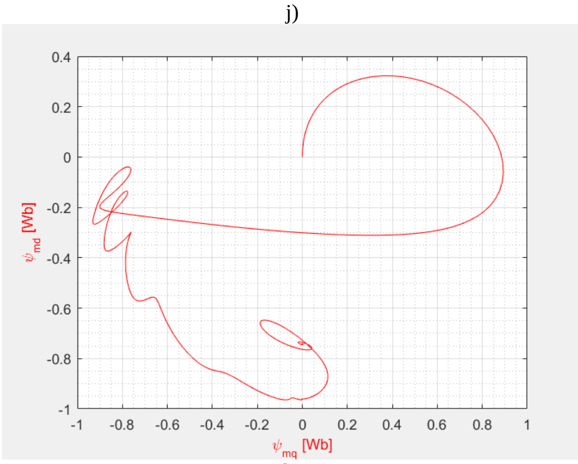
t [s]
j)


ψ_md [Wb]
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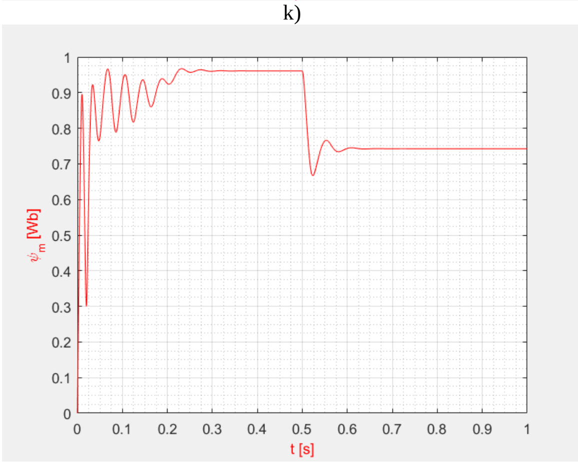
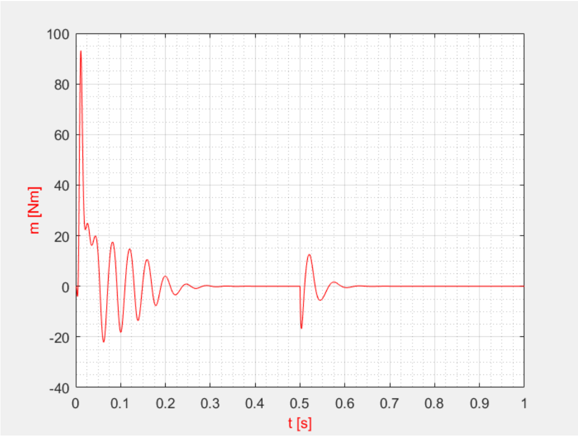
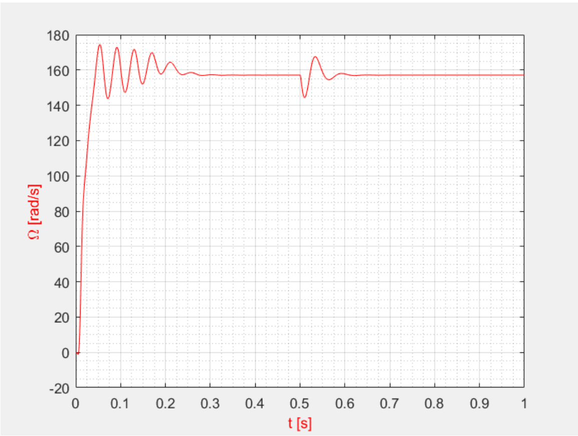
k)


ψ_m [Wb]
t [s]
l)



m)



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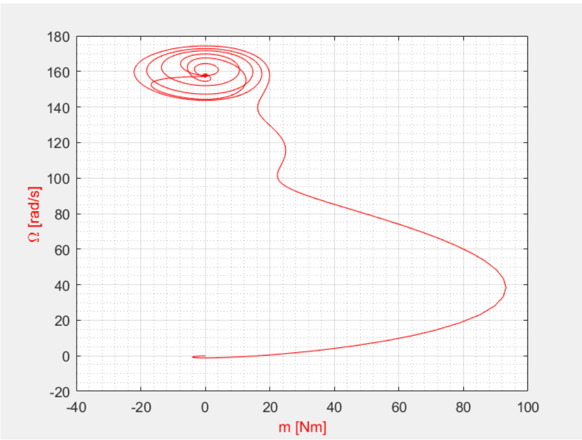

o)

Fig. 3. The characteristics obtained for the case of the decrease of the supply voltage value to 170 V, after 0.5 s from the no-load starting.

The situation refer to the decrease of the supply voltage value (Fig. 3 - the voltage decreases from the initial value of 220 V, down to 170 V);

The simulations were carried out for a motor rated as follows:

R_s = 3.77 Ω, R_D = 1.5 Ω, R_Q = 4.5 Ω, $L_{s\sigma}$ = 0.0081 H, $L_{D\sigma}$ = 0.0059 H, $L_{Q\sigma}$ = 0.0067 H, L_d=0.281 H, L_q=0.081 H; U = 220 V, p = 2, J=0.008 kg.m^2.

IV. Experimental Determinations

The electrical diagram of the measurement system is shown in figure 4.

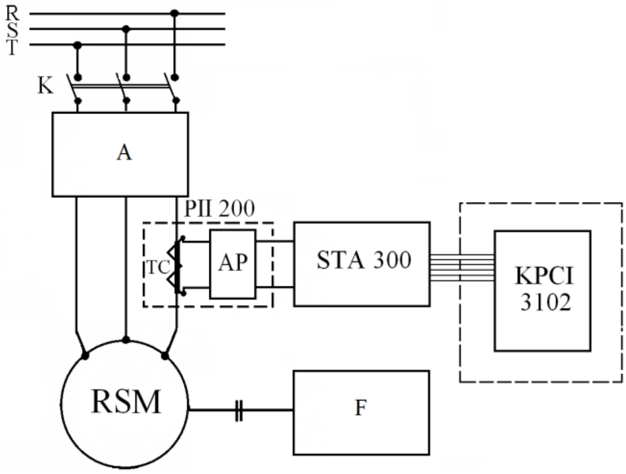

Fig. 4. Electrical diagram.

The meanings of the notations used are as follows:

- RSM – reluctance synchronous motor [11];
- A – autotransformer;
- F – fan;
- PII 200 - current transformer with adaptation block;
- STA 300 - connection block;
- KPCI 3102 - data acquisition board.

The motor used has a specially constructed rotor [12].

The rotor shaft is detailed in Fig. 5.

Its parameters are those used to obtain the simulations detailed previously.

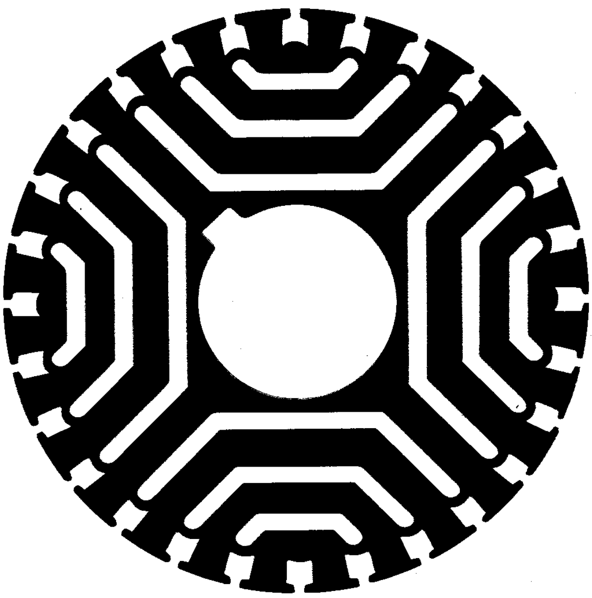
Fig. 5. The motor rotor shaft.

The experiments consisted in acquiring the current variations for a steady-state of the RSM, for two concrete situations:

- the steady-state operation at 220 V (Fig. 6);

- the steady-state operation at 170 V (Fig. 7).

Data were acquired by means of a data acquisition board, having a sampling frequency of 100 kHz [13].

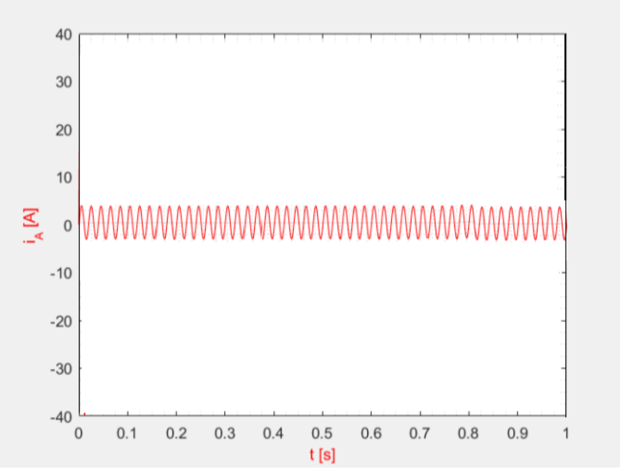

Fig. 6. The variation of the phase current, in case of steady-state operation, at 220 V.

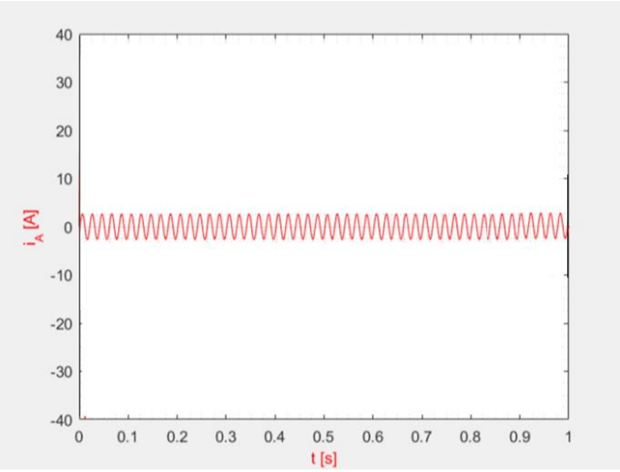

Fig. 7. The variation of the phase current, in case of steady-state operation, at 170 V.

Comparing these results with those depicted in Fig. 3.a (zone 0.3-0.5 s and zone 0.7-1 s), it is found that they are almost identical, which confirms the validity of the simulations (at least in steady state).

V. CONCLUSIONS

This paper presents a series of simulations that emphasize the dynamic regimes of RSM for industrial air heaters, in case of the supply voltage decrease.

General conclusion:

- the evolution of the operation point is suggestively visualized, especially in coordinates $\Omega = f(m)$.

Following the analysis of the simulations presented above, particular conclusions were obtained.

In the case of a decrease of the supply voltage value:

- a decrease in the voltage value leads to a decrease in the phase current;

- a decrease of the current also leads to a decrease in the magnetization flux;

- rotor speed is not affected.

ACKNOWLEDGMENT

Source of research funding in this article: Research program of the Electrical Engineering Faculty Craiova and the Faculty of Architecture Bucharest (financed by the University of Craiova).

Contribution of authors:
First author – 55 %;
First coauthor – 25 %;
Second coauthor – 20 %.

Received on September 17, 2024
Editorial Approval on December 2, 2024

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