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# Modeling of the Universal Cage Asynchronous Motor Command in Unbalanced Regime

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**Kalala Kalala[1,2], Ch. G. Lionel Nkouka Moukengue*[1], Flory Lidinga Mobonda[1], Narcisse Meni Babakidi[2], André Bandekela Kazadi [2]**

[1]*Laboratoire de Génie Electrique et Electronique, ENSP, Université Marien Ngouabi, RC, Congo-Brazzaville*

[2]*Laboratoire de Génie Electrique, ISTA, RDC, Congo-Brazzaville*

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## ABSTRACT

This article presents the different simulations of the behavior of a universal cage asynchronous motor in unbalanced regime for the case of overvoltage aiming at following the evolution of the operating parameters of the asynchronous motor in order to predict its operation and management; the different transformations such as Park, Concordia and Clark have been presented. This article focuses on the behavior of a cage asynchronous motor, used in electric drives, intended for intermittent duty operation. The torque constraints and the high inrush current in transient operation, caused by this mode of operation, are not without consequences on the motor itself and the related components of the electric drive. The behavior of the cage asynchronous motor at the first second of the machine operation has been described, when the undesirable dynamic phenomena appear. In this case, we consider the overvoltage of 20% of the nominal voltage on one or all three phases.

## INTRODUCTION

The DC motor was introduced in most industrial equipment because their linear structure made them easier to command. However, its main drawback remains the mechanical commutator which is not well tolerated in some environments and which increases maintenance costs. These constraints have oriented researchers towards the drive equipped with alternating current machines (synchronous and asynchronous) [1].

The command of asynchronous motors remains an open problem due to its nonlinear nature. The implementation of control laws for physical systems is a problem of growing interest. The joint progress of power electronics and digital electronics allows today to implement more and more complex control laws at lower costs. Thanks to these technological advances, the asynchronous machine is now more and more present in industrial applications.

The techniques of nonlinear command are based on the theory of differential geometry [1], among these techniques, the technique of linearization in the senses of input-state and input-output are the most important [2-6]. Several works [3-13] have shown that this nonlinear command technique has interesting properties regarding torque/flux decoupling, torque response time and parametric robustness. Its principle consists in finding a transformation which allows to compensate the nonlinearities of the model and thus to make the relation between the output of a system and its input completely linear [7-18].

The objective of this article is to describe the behavior of the cage induction motor at the first second of the machine operation, when the undesirable dynamic phenomena appear.

For this, we increase by 20% each stator voltage in order to have the voltage Vds and Vqs corresponding to the overvoltage. In this simulation, we study the evolution of the parameters of the machine in time when the overvoltage is observed on the three stator phases. The parameters to be observed are, the absorbed current, the electromagnetic torque, the slip and the rotation speed.

The orientation of this electric motor was voluntarily chosen in order to satisfy the requirements related to the exploitation of this asynchronous motor in unbalanced regime. These requirements are spread on several axes, and require the raising of several problems: The unbalanced regime of the machine, the robustness and good performances of the automatic real time control, the necessity of construction of management model for certain parameters and certain states of the asynchronous machine, to guarantee the same good performances for an operation in single phase.

**Modeling an asynchronous motor**

**Parck equations**

**Electrical equations in the d and q axes**

The electrical equations, of the asynchronous machine in the two-phase system, obtained by applying the Park transformation, are given as follows:

$$v_{s1} = R_s i_{s1} + L_s \frac{di_{s1}}{dt} + M\sqrt{\frac{2}{3}}\frac{di_{dr}}{dt} \quad (1)$$

$$v_{s2} = R_s i_{s2} + L_s \frac{di_{s2}}{dt} - \frac{M}{\sqrt{6}}\frac{di_{dr}}{dt} + \frac{M}{\sqrt{2}}\frac{di_{qr}}{dt} \quad (2)$$

$$v_{s3} = R_s i_{s3} + L_s \frac{di_{s3}}{dt} - \frac{M}{\sqrt{6}}\frac{di_{dr}}{dt} - \frac{M}{\sqrt{2}}\frac{di_{qr}}{dt} (3)$$

$$\begin{bmatrix} v_{s1} \\ v_{s2} \\ v_{s3} \end{bmatrix} = \begin{bmatrix} R_s + L_s P & 0 & 0 & M\sqrt{\frac{2}{3}}P & 0 \\ 0 & R_s + L_s P & 0 & -\frac{M}{\sqrt{6}}P & \frac{M}{\sqrt{2}}P \\ 0 & 0 & R_s + L_s P & -\frac{M}{\sqrt{6}}P & -\frac{M}{\sqrt{2}}P \end{bmatrix} \begin{bmatrix} i_{s1} \\ i_{s2} \\ i_{s3} \\ i_{dr} \\ i_{qr} \end{bmatrix} (4)$$

For reasons of simplification of the mathematical model, let us posit:

$$A_s = R_s + L_s P \quad (5)$$

$$A_r = R_r + L_r P \quad (6)$$

$$B = M\sqrt{\frac{2}{3}}P \quad (7)$$

$$C = \frac{M}{\sqrt{2}}P \quad (8)$$

$$D = \frac{M}{\sqrt{6}}P \quad (9)$$

$$E = \frac{M}{\sqrt{2}}W_r \ (10)$$

$$F = \frac{M}{\sqrt{6}}W_r \ (1)$$

$$G = L_r W_r \quad (12)$$

$$H = M\sqrt{\frac{2}{3}}W_r \ (13)$$

$$\begin{bmatrix} v_{s1} \\ v_{s2} \\ v_{s3} \end{bmatrix} = \begin{bmatrix} A_s & 0 & 0 & B & 0 \\ 0 & A_s & 0 & -C & D \\ 0 & 0 & A_s & -C & -D \end{bmatrix} \begin{bmatrix} i_{s1} \\ i_{s2} \\ i_{s3} \\ i_{dr} \\ i_{qr} \end{bmatrix} (14)$$

$$\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_r & 0 & 0 \\ 0 & R_r & 0 \\ 0 & 0 & R_r \end{bmatrix} \begin{bmatrix} i_{r1} \\ i_{r2} \\ i_{r3} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \varphi_{r1} \\ \varphi_{r2} \\ \varphi_{r3} \end{bmatrix} (15)$$

In a more condensed form:

$$[0] = [R_r][i_r] + \frac{d}{dt}[\varphi_r] \ (16)$$

$$[R_r] = \begin{bmatrix} R_r & 0 & 0 \\ 0 & R_r & 0 \\ 0 & 0 & R_r \end{bmatrix} \ (17)$$

$$[i_r] = \begin{bmatrix} i_{r1} \\ i_{r2} \\ i_{r3} \end{bmatrix} \quad (18)$$

$$[\varphi_r] = \begin{bmatrix} \varphi_{r1} \\ \varphi_{r2} \\ \varphi_{r3} \end{bmatrix} (19)$$

$$[0] = [R_r][i_r] + \frac{d}{dt}[\varphi_r] \Leftrightarrow 0 = [R_r][P(\theta r)^{-1}][i_{pr}] + \frac{d}{dt}[\varphi_r] + \frac{d}{dt}\{[P(\theta r)^{-1}]\ [\varphi_{pr}]\}\ (20)$$

$$0 = [R_r][P(\theta r)^{-1}][i_{pr}] + \frac{d[P(\theta r)^{-1}]}{d\theta r}[\varphi_{pr}] + [P(\theta r)^{-1}]\frac{d\varphi_{pr}}{dt}\ (21)$$

Multiplying on the left by $[P(\theta_r)]$

$$0 = [R_r][i_{pr}] + [P(\theta_r)]\frac{d[P(\theta r)^{-1}]}{d\theta r}[\varphi_{pr}] + [P(\theta r)^{-1}]\frac{d[\varphi_{pr}]}{dt}(22)$$

$$[P(\theta_r)]\frac{d[P(\theta r)^{-1}]}{d\theta r} = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}(23)$$

$$\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_r & 0 & 0 \\ 0 & R_r & 0 \\ 0 & 0 & R_r \end{bmatrix}\begin{bmatrix} i_{dr} \\ i_{qr} \\ i_{0r} \end{bmatrix} + \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} \varphi_{dr} \\ \varphi_{qr} \\ \varphi_{0r} \end{bmatrix}\left(\frac{d\theta r}{dt}\right) + \frac{d}{dt}\begin{bmatrix} \varphi_{dr} \\ \varphi_{qr} \\ \varphi_{0r} \end{bmatrix}(24)$$

Assuming zero homopolar components, we find:

$$0 = \frac{d\varphi_{dr}}{dt} - \varphi_{qr}\frac{d\theta r}{dt} + R_r i_{dr}\ (25)$$

$$0 = \frac{d\varphi_{qr}}{dt} - \varphi_{dr}\frac{d\theta r}{dt} + R_r i_{qr}(26)$$

$$0 = M\sqrt{\frac{2}{3}}\frac{di_{s1}}{dt} - \frac{M}{\sqrt{6}}\frac{di_{s2}}{dt} - \frac{M}{\sqrt{2}}\frac{d\theta r i_{s2}}{dt} - \frac{M}{\sqrt{6}}\frac{di_{s3}}{dt} + \frac{M}{\sqrt{2}}\frac{d\theta r i_{s3}}{dt} + L_r\frac{di_{dr}}{dt} + R_r i_{r1} - L_r\frac{d\theta r\, i_{qr}}{dt}$$

$$0 = M\sqrt{\frac{2}{3}}\frac{d\theta r\, i_{s1}}{dt} + \frac{M}{\sqrt{2}}\frac{di_{s2}}{dt} - \frac{M}{\sqrt{6}}\frac{d\theta r i_{s2}}{dt} - \frac{M}{\sqrt{2}}\frac{di_{s3}}{dt} + L_r\frac{d\theta r i_{dr}}{dt} + L_r\frac{di_{dr}}{dt} + R_r i_{qr}$$

Knowing that:

$$\frac{d\theta r}{dt} = -w_r$$

The system of equations becomes:

$$0 = M\sqrt{\frac{2}{3}}\frac{di_{s1}}{dt} - \frac{M}{\sqrt{6}}\frac{di_{s2}}{dt} - \frac{M}{\sqrt{2}}w_r i_{s2} - \frac{M}{\sqrt{6}}\frac{di_{s3}}{dt} - \frac{M}{\sqrt{2}}w_r i_{s3} + L_r\frac{di_{dr}}{dt} + R_r i_{dr} - L_r w_r i_{qr} \quad (27)$$

$$0 = -M\sqrt{\frac{2}{3}}w_r i_{s1} + \frac{M}{\sqrt{2}}\frac{di_{s2}}{dt} + \frac{M}{\sqrt{6}}w_r i_{s2} - \frac{M}{\sqrt{2}}\frac{di_{s3}}{dt} + \frac{M}{\sqrt{6}}w_r i_{s3} - L_r w_r i_{dr} + L_r\frac{di_{qr}}{dt} + R_r i_{qr} \quad (28)$$

In matrix form:

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} B & -C+E & -C-E & A_r & G \\ -H & D+F & -D+F & -G & A_r \end{bmatrix}\begin{bmatrix} i_{s1} \\ i_{s2} \\ i_{s3} \\ i_{dr} \\ i_{qr} \end{bmatrix}$$

By grouping the matrix systems we obtain:

$$\begin{bmatrix} v_{s1} \\ v_{s2} \\ v_{s3} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} A_s & 0 & 0 & B & 0 \\ 0 & A_s & 0 & -C & D \\ 0 & 0 & A_s & -C & -D \\ B & -C+E & -C-E & A_r & G \\ -H & D+F & -D+F & -G & A_r \end{bmatrix}\begin{bmatrix} i_{s1} \\ i_{s2} \\ i_{s3} \\ i_{dr} \\ i_{qr} \end{bmatrix} \quad (29)$$

**Overvoltage equation**

**Voltage equations related to a 20% overvoltage on one phase**

$$\boldsymbol{V_s} = \begin{bmatrix} 264\sqrt{2}\cos(\omega t) \\ 220\sqrt{2}\cos\left(\omega t - \frac{2\pi}{3}\right) \\ 220\sqrt{2}\cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \quad (30)$$

$$\begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} = T_{23} \begin{bmatrix} V_{S1} \\ V_{S2} \\ V_{S3} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} V_{S1} - \frac{V_{S2}}{2} - \frac{V_{S3}}{2} \\ \frac{\sqrt{3}}{2}(V_{S2} - V_{S3}) \end{bmatrix} = \frac{2\sqrt{3}}{2} \begin{bmatrix} 374\cos(\omega t) \\ 330\sin(\omega t) \end{bmatrix} (31)$$

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = P(-\omega t) \begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} = 44\frac{\sqrt{3}}{3} \begin{bmatrix} 16 + \cos(2\omega t) \\ -\sin(2\omega t) \end{bmatrix} (32)$$

**Equation of the 20% voltage drop on one phase**

$$V_s = \begin{bmatrix} 176\sqrt{2}\cos(\omega t) \\ 220\sqrt{2}\cos\left(\omega t - \frac{2\pi}{3}\right) \\ 220\sqrt{2}\cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} (33)$$

$$\Rightarrow \begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} = T_{23} \begin{bmatrix} V_{S1} \\ V_{S2} \\ V_{S3} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} V_{S1} - \frac{V_{S2}}{2} - \frac{V_{S3}}{2} \\ \frac{\sqrt{3}}{2}(V_{S2} - V_{S3}) \end{bmatrix} = \frac{2\sqrt{3}}{2} \begin{bmatrix} 286\cos(\omega t) \\ 330\sin(\omega t) \end{bmatrix} (34)$$

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = P(-\omega t) \begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} = 44\frac{\sqrt{3}}{3} \begin{bmatrix} 14 - \cos(2\omega t) \\ -\sin(2\omega t) \end{bmatrix} (35)$$

**Simulation of the motor in unbalanced regime**

**Current of one motor phase in case of 3-phase overvoltage**

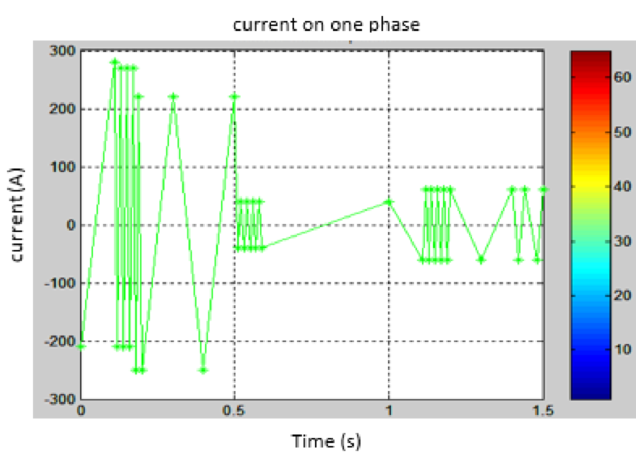


**Figure 1: Current of one phase of the motor during a 3-phase overvoltage.**

**Motor torque after overvoltage on all three phases**

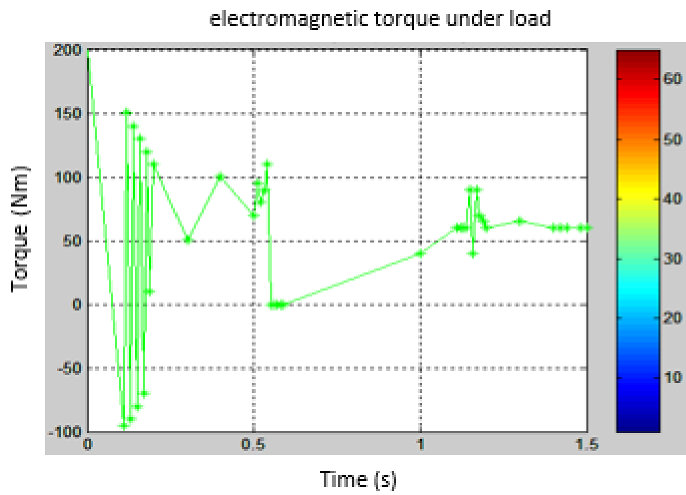


**Figure 2: Motor torque after overvoltage on all three phases**

**Motor rotation velocity in case of 3-phase overvoltage**

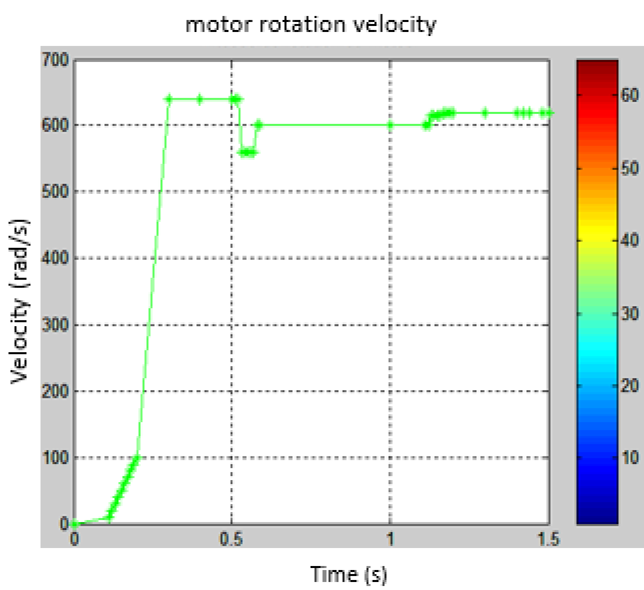


**Figure 3: Motor rotation velocity in case of 3-phase overvoltage**

**Variation of motor slip in case of 3-phase overvoltage**

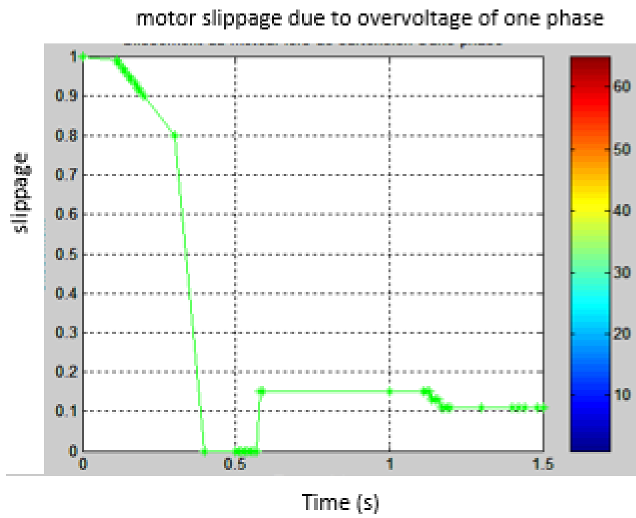


**Figure 4: Variation of motor slip in case of 3-phase overvoltage**

**Current of one phase of the motor in case of overvoltage of one phase**

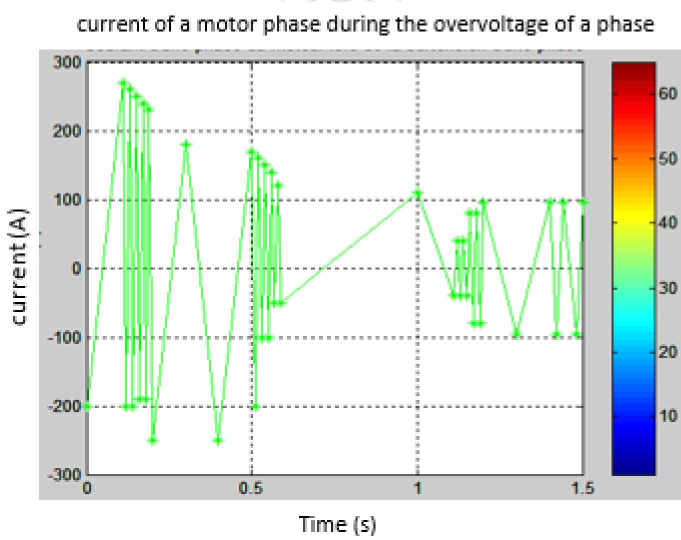


**Figure 5: Current of one phase of the motor in case of overvoltage of one phase**

**Couple électromagnétique lors de surtension d'une phase**

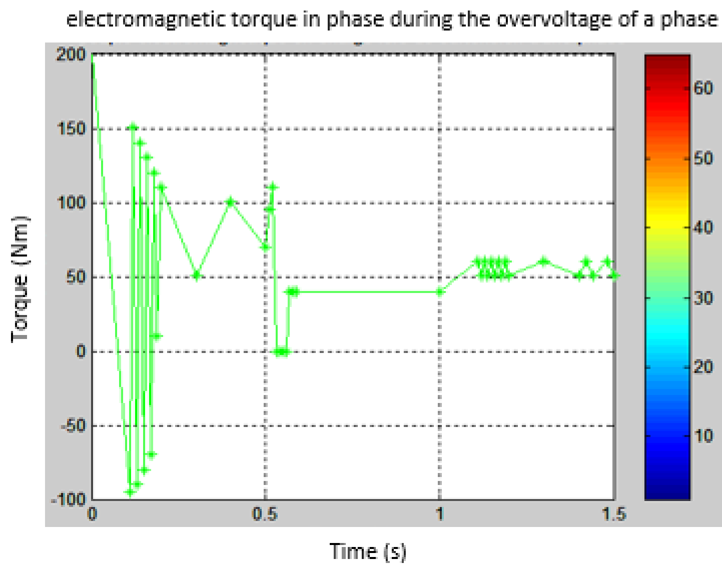


**Figure 6: Electromagnetic torque in case of overvoltage of one phase**

**Velocity of rotation in case of overvoltage of one phase**

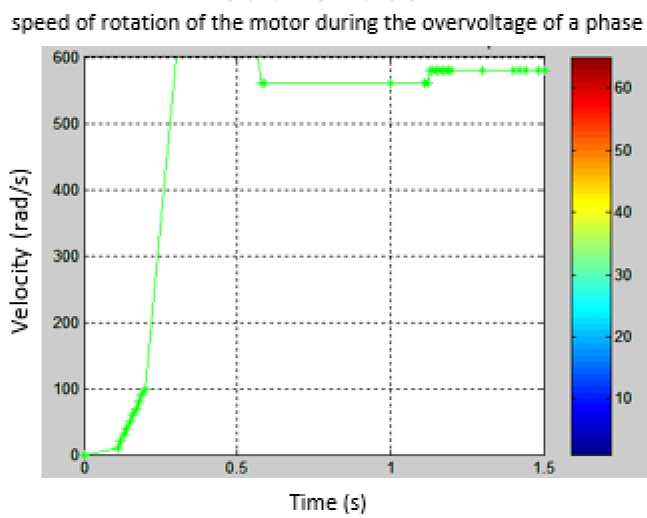


**Figure 7: Velocity of rotation in case of overvoltage of one phase**

**Slippage during overvoltage of a phase**

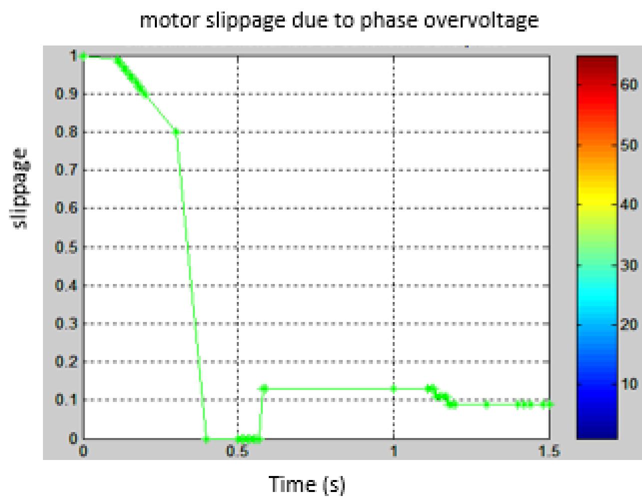


**Figure 8: Slippage during overvoltage of a phase**

When the overvoltage appears at t=1s, the absorbed stator currents increase and then drop to follow a new steady state (figures 1 and 5). Taking into account the torque, given the overvoltage, a new transient regime appears between the moment of the fault at t=1 s and t=1.15 s, the torque goes from 53.86 N.m to 95.19 N.m before stabilizing at a constant torque of 56.28 N.m at about 1.2 s.

The velocity increases just slightly from 295 rad/s to 301 rad/s, which leads to a slight decrease in slip (figures 4 and 7). In view of the high current increases, abnormal heating of the machine is to be feared even at low load operation.

During the overvoltage on the phase concerned, the current increases considerably following a new steady state, which has an impact on the heating of the conductors and therefore of the machine (figures 1 and 5). The torque becomes oscillating, it varies without reaching a fixed value for any stability (figures 2 and 6). The speed varies very little from 295 rad/s to 297 rad/s, the slip becomes smaller and smaller.

**CONCLUSION**

This article consisted in modeling the control of the asynchronous motor with cage. The models of the control used translate the equations of the variations of the parameters of the motor during overvoltage of a phase. We applied these models on the universal cage induction motor and simulated it by a Matlab program.

We note that what makes the difference between the overvoltage on three phases and the overvoltage on one phase is that the electromagnetic torque does not vary in the same way, the overvoltage on the three phases tends to approach the same paces as in nominal voltage with an increase of the parameters (torque, stator current, speed) in terms of amplitude, on the other hand an increase of voltage on one phase makes the torque unstable and thus variable in time. In both cases we notice that the stator current and the speed increase in the machine and the slip seems to tend towards zero.

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