Research Journal of Recent Sciences ISSN 2277-2502
Vol. **15(4),** 25-29, October **(2026)** *Res. J. Recent Sci.*

Modeling of the control of a Universal three-monophasical Asynchronous motor in unbalanced Regimen during Phase overvoltage

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Available online at: www.isca.in, www.isca.me
Received 15th April 2026, revised 13th May 2026, accepted 8th August 2026

Abstract

This article presents various simulation scenarios for the behavior of a three-phase universal squirrel-cage induction motor under unbalanced conditions for overvoltage. The aim is to monitor the evolution of the motor's operating parameters in order to predict its performance and management. Different transformations, such as Park, Concordia, and Clark, are presented. This article focuses primarily on the behavior of a squirrel-cage induction motor used in electrical drives designed for intermittent operation. The torque constraints and high inrush currents during transient operation, caused by this mode of operation, have significant consequences for the motor itself and the associated components of the electrical drive. The aim of this article is to describe the behavior of the squirrel-cage induction motor in the first second of machine operation, when undesirable dynamic phenomena appear. In this case, we consider an overvoltage of 20% of the nominal voltage on one or all three phases.

Keywords: Modeling, Control, Asynchronous squirrel-cage motor, Three-phase, Unbalanced regime, Phase overvoltage.

Introduction

For this simulation we increase deach stator voltage by 20% in order to have the Vds and Vqs voltages corresponding to the overvoltage[1]. The expressions for Vds and Vq so btained are: Vds = $264\sqrt{3}$ and Vqs = 0[2]. This simulation studies the evolution of the machine's parameters over time when over voltage is observed on all three stator phases[3]. The parameters to be observed are the current drawn, the electromagnetic torque, the slip, and the rotational speed.

He orientation of this electricmotor was deliberately chosen to meet the requirements related to operating this asynchronous motor in unbalanced conditions[4]. These requirements are multifaceted and necessitatead dressing several issues: the unbalanced operating conditions of the machine, the robustness and high performance of the real-time automaticcontrol, the need to develop a management model for certain parameters and states of the asynchronous machine, and ensuring the same high performance for single-phase operation[5-7].

Modeling of an asynchronous motor

Park's equations: Electrical equations in the d and q axes

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

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

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

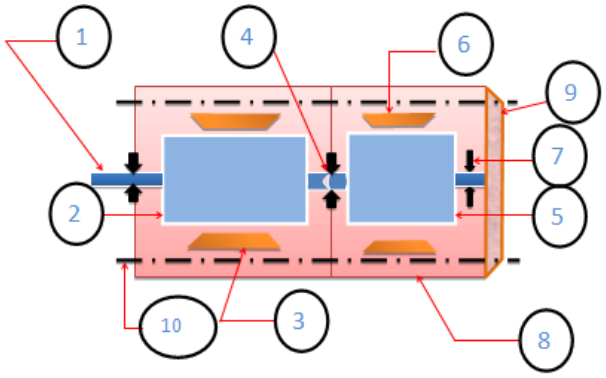


Figure-1: MACU principle diagram.
Legend: 1. Drive shaft or transmission, 2. Single-phase rotor, 3. Single-phase winding, 4. Levels, 5. Three-phase rotor, 6. Three-phase winding, 7. Bearing.

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

For the sake of simplifying the mathematical model, let us assume:

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

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

$$\begin{bmatrix} v_{s1} \\ v_{s2} \\ v_{s3} \end{bmatrix} = \begin{bmatrix} A_s & 0 & 0 & B & 0 \\ 0 & A_s & 0 & -C & D \\ 0 & 0 & A_s & -C & -D \end{bmatrix} \begin{bmatrix} i_{s1} \\ i_{s2} \\ i_{s3} \\ i_{dr} \\ i_{qr} \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_r & 0 & 0 \\ 0 & R_r & 0 \\ 0 & 0 & R_r \end{bmatrix} \begin{bmatrix} i_{r1} \\ i_{r2} \\ i_{r3} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \varphi_{r1} \\ \varphi_{r2} \\ \varphi_{r3} \end{bmatrix} \quad (8)$$

In a more condensed form:

$$[0] = [R_r][i_r] + \frac{d}{dt}[\varphi_r] \quad (9)$$

$$[R_r] = \begin{bmatrix} R_r & 0 & 0 \\ 0 & R_r & 0 \\ 0 & 0 & R_r \end{bmatrix} \quad (10)$$

$$[i_r] = \begin{bmatrix} i_{r1} \\ i_{r2} \\ i_{r3} \end{bmatrix} \quad (11)$$

$$[\varphi_r] = \begin{bmatrix} \varphi_{r1} \\ \varphi_{r2} \\ \varphi_{r3} \end{bmatrix} \quad (12)$$

$$[0] = [R_r][i_r] + \frac{d}{dt}[\varphi_r] \Leftrightarrow 0 = [R_r][P(\theta r)^{-1}][i_{pr}] + \frac{d}{dt}[\varphi_r] + \frac{d}{dt}\{[P(\theta r)^{-1}][\varphi_{pr}]\} \quad (13)$$

$$0 = [R_r][P(\theta r)^{-1}][i_{pr}] + \frac{d[P(\theta r)^{-1}]}{d\theta r}[\varphi_{pr}] + [P(\theta r)^{-1}]\frac{d\varphi_{pr}}{dt} \quad (14)$$

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

$$0 = [R_r][i_{pr}] + [P(\theta_r)]\frac{d[P(\theta r)^{-1}]}{d\theta r}[\varphi_{pr}] + [P(\theta r)^{-1}]\frac{d[\varphi_{pr}]}{dt} \quad (15)$$

$$[P(\theta_r)]\frac{d[P(\theta r)^{-1}]}{d\theta r} = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (16)$$

$$\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_r & 0 & 0 \\ 0 & R_r & 0 \\ 0 & 0 & R_r \end{bmatrix} \begin{bmatrix} i_{dr} \\ i_{qr} \\ i_{0r} \end{bmatrix} + \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \varphi_{dr} \\ \varphi_{qr} \\ \varphi_{0r} \end{bmatrix} \left(\frac{d\theta r}{dt}\right) + \frac{d}{dt} \begin{bmatrix} \varphi_{dr} \\ \varphi_{qr} \\ \varphi_{0r} \end{bmatrix} \quad (17)$$

Assuming the homopolar components are zero, we find:

$$0 = \frac{d\varphi_{dr}}{dt} - \varphi_{qr}\frac{d\theta r}{dt} + R_r i_{dr} \quad (18)$$

$$0 = \frac{d\varphi_{qr}}{dt} - \varphi_{dr}\frac{d\theta r}{dt} + R_r i_{qr} \quad (19)$$

$$0 = M\sqrt{\frac{2}{3}}\frac{di_{s1}}{dt} - \frac{M}{\sqrt{6}}\frac{di_{s2}}{dt} - \frac{M}{\sqrt{2}}\frac{d\theta r\, i_{s2}}{dt} - \frac{M}{\sqrt{6}}\frac{di_{s3}}{dt} + \frac{M}{\sqrt{2}}\frac{d\theta r\, i_{s3}}{dt} + L_r\frac{di_{dr}}{dt} + R_r i_{r1} - L_r\frac{d\theta r\, i_{qr}}{dt} \quad (20)$$

$$0 = M\sqrt{\frac{2}{3}}\frac{d\theta r\, i_{s1}}{dt} + \frac{M}{\sqrt{2}}\frac{di_{s2}}{dt} - \frac{M}{\sqrt{6}}\frac{d\theta r\, i_{s2}}{dt} - \frac{M}{\sqrt{2}}\frac{di_{s3}}{dt} + L_r\frac{d\theta r\, i_{dr}}{dt} + L_r\frac{di_{dr}}{dt} + R_r i_{qr} \quad (21)$$

Knowing that:

$$\frac{d\theta r}{dt} = -w_r \quad (22)$$

The system of equations becomes:

$$0 = M\sqrt{\frac{2}{3}}\frac{di_{s1}}{dt} - \frac{M}{\sqrt{6}}\frac{di_{s2}}{dt} - \frac{M}{\sqrt{2}}w_r i_{s2} - \frac{M}{\sqrt{6}}\frac{di_{s3}}{dt} - \frac{M}{\sqrt{2}}w_r i_{s3} + L_r\frac{di_{dr}}{dt} + R_r i_{dr} - L_r w_r i_{qr} \quad (23)$$

$$= -M\sqrt{\frac{2}{3}}w_r i_{s1} + \frac{M}{\sqrt{2}}\frac{di_{s2}}{dt} + \frac{M}{\sqrt{6}}w_r i_{s2} - \frac{M}{\sqrt{2}}\frac{di_{s3}}{dt} + \frac{M}{\sqrt{6}}w_r i_{s3} - L_r w_r i_{dr} + L_r\frac{di_{qr}}{dt} + R_r i_{qr} \quad (24)$$

In matrix form:

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} B & -C+E & -C-E & A_r & G \\ -H & D+F & -D+F & -G & A_r \end{bmatrix} \begin{bmatrix} i_{s1} \\ i_{s2} \\ i_{s3} \\ i_{dr} \\ i_{qr} \end{bmatrix} \quad (25)$$

By grouping matrix systems, we obtain:

$$\begin{bmatrix} v_{s1} \\ v_{s2} \\ v_{s3} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} A_s & 0 & 0 & B & 0 \\ 0 & A_s & 0 & -C & D \\ 0 & 0 & A_s & -C & -D \\ B & -C+E & -C-E & A_r & G \\ -H & D+F & -D+F & -G & A_r \end{bmatrix} \begin{bmatrix} i_{s1} \\ i_{s2} \\ i_{s3} \\ i_{dr} \\ i_{qr} \end{bmatrix} \quad (26)$$

Overvoltage equation

Voltage equations related to a 20% overvoltage on one phase

$$\boldsymbol{V_s} = \begin{bmatrix} 264\sqrt{2}\cos(\omega t) \\ 220\sqrt{2}\cos\left(\omega t - \frac{2\pi}{3}\right) \\ 220\sqrt{2}\cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \quad (27)$$

$$\begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} = T_{23}\begin{bmatrix} V_{S1} \\ V_{S2} \\ V_{S3} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} V_{S1} - \frac{V_{S2}}{2} - \frac{V_{S3}}{2} \\ \frac{\sqrt{3}}{2}(V_{S2} - V_{S3}) \end{bmatrix} = \frac{2\sqrt{3}}{2}\begin{bmatrix} 374\cos(\omega t) \\ 330\sin(\omega t) \end{bmatrix} \quad (28)$$

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = P(-\omega t)\begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} = 44\frac{\sqrt{3}}{3}\begin{bmatrix} 16 + \cos(2\omega t) \\ -\sin(2\omega t) \end{bmatrix} \quad (29)$$

Equation for a 20% voltage drop on one phase

$$V_s = \begin{bmatrix} 176\sqrt{2}\cos(\omega t) \\ 220\sqrt{2}\cos\left(\omega t - \frac{2\pi}{3}\right) \\ 220\sqrt{2}\cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \quad (30)$$

$$\Rightarrow \begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} = T_{23} \begin{bmatrix} V_{S1} \\ V_{S2} \\ V_{S3} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} V_{S1} - \frac{V_{S2}}{2} - \frac{V_{S3}}{2} \\ \frac{\sqrt{3}}{2}(V_{S2} - V_{S3}) \end{bmatrix} = \frac{2\sqrt{3}}{2} \begin{bmatrix} 286cos(\omega t) \\ 330sin(\omega t) \end{bmatrix} \quad (31)$$

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = P(-\omega t) \begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} = 44\frac{\sqrt{3}}{3} \begin{bmatrix} 14 - cos(2\omega t) \\ -sin(2\omega t) \end{bmatrix} \quad (32)$$

Modeling the engine unbalanced regimen

Simulation of the MACU engine: Current of one phase of the motor during a 3-phase overvoltage, Motor torque after a three-phase overvoltage, Motor rotation speed during a 3-phase overvoltage, Variation of motor slip during 3-phase overvoltage, Current of one phase of the motor during a phase overvoltage, Electromagnetic torque during single-phase overvoltage, Rotation speed during single-phase overvoltage, Slippage during phase overvoltage are as fellows.

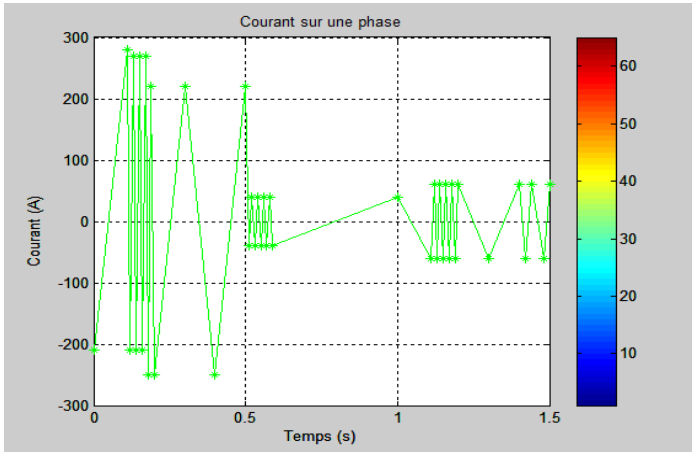


Figure-2: Current of one phase of the motor during overvoltage of 3 phases.

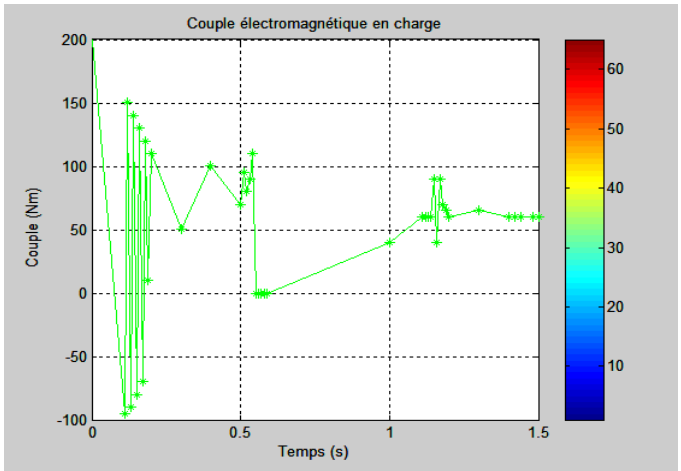


Figure-3: Motor torque after a three-phase overvoltage.

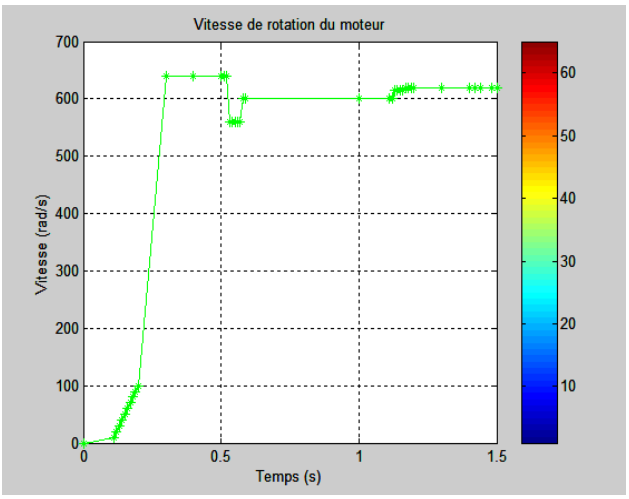


Figure-4: Motor rotation speed during 3-phase overvoltage.

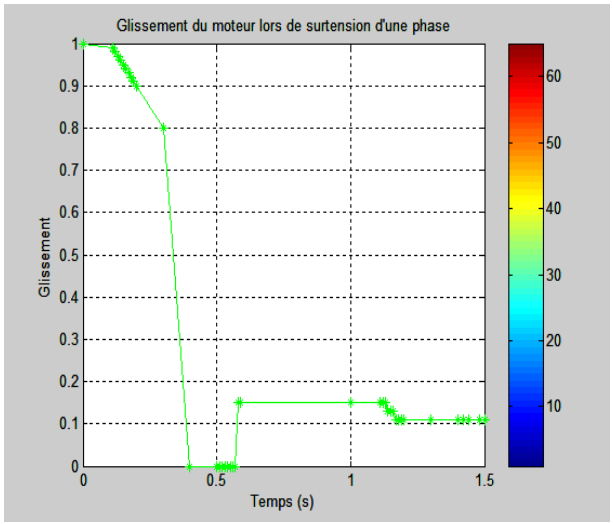


Figure-5: Variation of motor slip during 3-phase overvoltage.

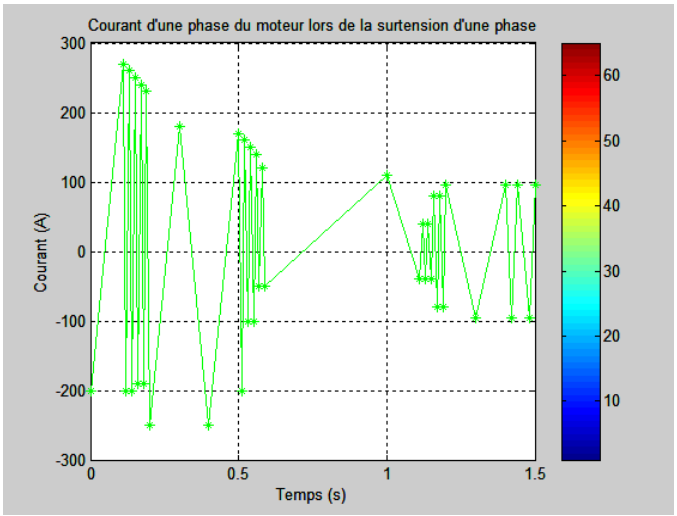


Figure-6: Current of one phase of the motor during a single-phase overvoltage

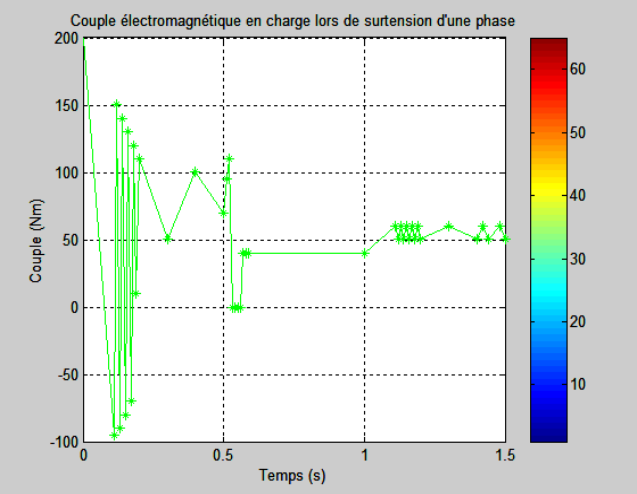


Figure-7: Electromagnetic torque during single-phase overvoltage.

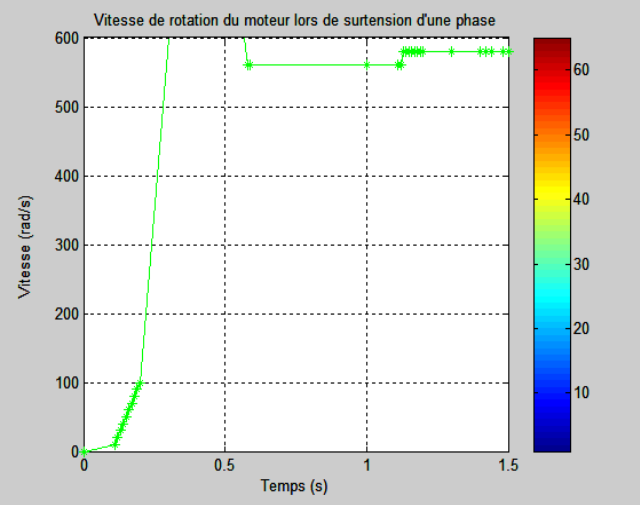


Figure-8: Rotation speed during single-phase overvoltage.

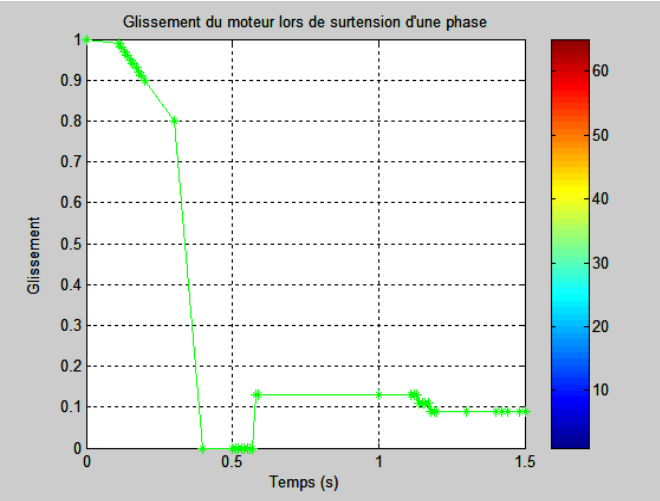


Figure-9: Slippage during phase overvoltage.

Interpretation of results: When the overvoltage occurs at t=1s, the stator currents drawn increase and then fall to reach a new steady state. Given the torque and the overvoltage, a new transient regime appears between the time of the fault at t=1 s and t=1.15 s. The torque increases from 53.86 Nm to 95.19 Nm before stabilizing at a constant torque of 56.28 Nm at approximately 1.2 s. The speed increases only slightly from 295 rad/s to 301 rad/s, resulting in a slight decrease in slip. Due to the significant current increases, abnormal heating of the machine, even under light load operation, is a concern.

During an overvoltage on the affected phase, the current increases considerably, following a new steady-state regime. This impacts the heating of the conductors and therefore the machine. The torque becomes oscillatory, varying without reaching a fixed value for any stability. The speed varies very little, from 295 rad/s to 297 rad/s, and the slip becomes increasingly small.

Conclusion

This article focused on modeling the control of a squirrel-cage induction motor. The control models used represent the equations for the variation of motor parameters during a single-phase overvoltage. We applied these models to a universal squirrel-cage induction motor and simulated it using a program in the Matlab environment.

We observe that the difference between a three-phase overvoltage and a single-phase overvoltage is that the electromagnetic torque does not vary in the same way. A three-phase overvoltage tends to exhibit the same waveforms as at nominal voltage, with an increase in the parameters (torque, stator current, speed) in terms of amplitude. Conversely, a voltage increase on a single phase makes the torque unstable and therefore variable over time. In both cases, however, we note that the stator current and the speed increase in the machine, and the slip appears to tend towards zero.

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