ISSN No:-2456-2165

Modeling of the Synchronous Cascade Control Industrial Ring Motor from the Bralima Company

Mbengayi Kabamukoyi[1], Lidinga Mobonda Flory[2], Haroun Abba Labane[3],
Okemba Rodrigue Armel Patrick[4], Bandekela Kazadi André[5]

Abstract:- In this article, we present the modeling of the synchronous cascade control of an industrial ring motor of the Brasserie de Kinshasa; based on nonlinear equations based on the operations of varying speeds in real time. Conventional control, where the mains voltage is applied directly to the ring motor does not offer the possibility of varying the speed of said motor.

The objective of this article is to vary the speed of the motor beyond synchronism. Conventional control, where the mains voltage is applied directly to the ring motor does not offer the possibility of varying the speed of said motor.

The mathematical model based on the nonlinear equations of the electromechanical quantities of the motor facilitate the evaluation of the performance of the slip ring motor. These models confirm that the variation in the speed of the ring motor is closely related to the power of the converter associated with the stator and the rotor.

Keywords:- *Modeling, Control, Synchronous Cascade, Industrial Motor, Ring.*

I. INTRODUCTION

Among the techniques for controlling the asynchronous machine by acting on the slip, the hypo-synchronous cascade (the recovery of secondary power). The speed of the asynchronous slip ring motor supplied directly by the network at constant voltage and frequency can be adjusted by acting on the power taken between the rings.

The need for static converters is justified by the fact that: The rectifier has the role of rectifying three-phase voltages, and the non-autonomous inverter (frequency conversion) is responsible for converting voltage and frequency.

The transformation ratio of the asynchronous machine with open rotor is designated by m, that of the three-phase transformer by K_T. The alternating current of the rotor, at the pulsation $g\omega_S$, is rectified then filtered by an inductance coil L. A assisted inverter ensures the DC-AC conversion at the network frequency. The power returned to the network and therefore the speed of the motor is regulated by acting on the delay angle at the firing of the inverter thyristors. A three-phase transformer is required to match the output voltage of the inverter to that of the grid.

I.1 OPERATION OF THE HYPOSYNCHRONE CASCADE

I.1.1 Calculation of voltage U_d

Single rotor voltages have:
A pulsation $g\omega$.
An amplitude

$$V_r = mg.V_s \quad (1.1)$$

With:

V_s: amplitude of the phase-to-neutral supply voltages and m: ratio of no-load voltages with the rotor stopped (g = 1).

The rectified six-diode bridge delivers a rectified voltage of average value when empty:

$$U_d = \frac{3\sqrt{3}\,V_r}{\pi} = \frac{3\sqrt{3}kgV_s}{\pi} \quad (1.2)$$

The delay angle of the bridge with six thyristors operating as an inverter is denoted by α.

I.1.2 No load

$$U_d = \frac{3\sqrt{3}\,mgV_r}{\pi} \quad (1.3)$$

The relationship between the voltages on the DC side and the AC side is written:

$$U_d = \frac{3\sqrt{3}V_s}{\pi}K_T cos\alpha \quad (1.4)$$

The comparison of the two expressions gives: on the inverter side

$$g = g_0 = -\frac{K_T}{m}cos\alpha \quad (1.5)$$

A vacuum ΔU_d is negligible, the slip differs little from

$$g_0 = -\frac{K_T}{m}cos\alpha$$

This relation shows how we increase the slip by increasing | cosα |. By varying

α $:\frac{\pi}{2} < \alpha < \frac{5\pi}{6} \Rightarrow 0 < |cos\alpha| < \frac{\sqrt{3}}{2}$, that is to say, we vary g_0:

$$0 < g_0 < \frac{\sqrt{3}}{2} \cdot \frac{K_T}{m} \qquad (1.6)$$

The maximum slip is therefore proportional to the rotor voltage at standstill; this is only if V_r equals V_s hence the operation at very low speed.

In this range of α, g is always positive, that is to say that the machine operates as a motor, hence the name hyposynchronous. If α <π / 2, g is negative, that is to say that the machine operates as a generator (hypersynchronous).

I.1.3 In charge

Because of the internal resistance of the motor, in particular its reactance, the rectified voltage, when the flow of current Id assumed to be constant, is:

$$U_d = \frac{3\sqrt{3}\, mgV_s}{\pi} - \Delta U_d \quad (1.6)$$

The comparison of the two expressions gives:

$$U_d = \frac{3\sqrt{3}\, mgV_s}{\pi} - \Delta U_d = \frac{3\sqrt{3}V_s}{\pi} cos\alpha$$

Which gives the final expression of sliding under load:

$$g = -\frac{K_T}{m} cos\alpha + \frac{\Delta U_d}{\frac{3\sqrt{3}\, mV_s}{\pi}} \qquad (1.7)$$

Under load, at │cosα│ given, the increase in torque results in an increase in current Id, that is to say in the voltage drop ΔU_d, therefore the variation in slip.

I.1.2. Torque equation

The power taken from the terminals of the rotor is U_d I_d, it is equal to the product of the slip by the power P_{em} crossing the air gap. In addition, the torque C is the quotient of this power by the synchronous angular speed Ω_s:

$$U_d I_d = gP_{ém} = gC_{ém}\Omega_s \qquad (1.7)$$

$$P_{ém} = \frac{U_d I_d}{g\Omega_s} = I_d \frac{\frac{3\sqrt{3}\, mgV_s}{\pi}}{g\Omega_s} \qquad (1.8)$$

The voltage drop ΔU_d causes the torque to not grow quite proportional to the current Id. The shape of C (Ω) for various values of α between π/ 2 and 5/6 π.

I.2. SYNCHRONOUS CASCADE EQUATIONS

I.2.1 Bridge Rectifier

It is known that the frequency of the rotor is different from that of the stator, which requires an indirect return of the energy to the stator. This indirect return requires a three-phase rectifier with diodes in bridge.

$$U_d = U_{d0} - \Delta U_s = \frac{3\sqrt{3}\, mgV_s}{\pi} - 2R_2 I_d - \frac{3gX_2 I_d}{\pi} (1.9)$$

$$U_d = \frac{3\sqrt{3}\, mgV_s}{\pi} - \left(2R_2 + \frac{3gX_2}{\pi}\right) I_d \quad (3.10)$$

According to these two equations the power dissipated at the output is:

$$P = U_d I_d = \frac{3\sqrt{3}\, mgV_s}{\pi} I_d - \left(2R_2 + \frac{3gX_2}{\pi}\right) I_d^2 \quad (3.11)$$

I.2.2 Inverter bridge

The return of power P to the network which passes through the rectifier requires an inverter so that the power is at the same frequency. The voltage at the inverter is:

$$U'_d = U_d cos\alpha - \Delta U'_d \qquad (1.12)$$

$$U_d = \frac{3\sqrt{3}\, K_T V_s cos\alpha}{\pi} - \left(2R_T + 3\frac{X_T}{\pi}\right) I_d \ (1.13)$$

The power returned to the network is worth:

$$P = U_d' I_d = \frac{3\sqrt{3}\, K_T V_s cos\alpha}{\pi} I_d - \left(2R_T + 3\frac{X_T}{\pi}\right) I_d^2 \ (1.14)$$

According to the mesh law, the average values of the rectifier and inverter voltages are equal:

$$U_d = U'_d \Rightarrow \frac{3\sqrt{3}\, K_T V_s cos\alpha}{\pi} I_d - \left(2R_T + 3\frac{X_T}{\pi}\right) I_d \ (1.15)$$

$$U_d = U'_d = \frac{3\sqrt{3}\, mgV_s}{\pi} I_d - \left(2R_T + \frac{3gX_2}{\pi}\right) I_d \ (1.16)$$

We leave the final formula of the slip as a function of the load, the supply voltage and the firing angle of the thyristors.

$$g = \frac{-\sqrt{3}\, K_T V_s cos\alpha + \left(X_T + \frac{2\pi R_T}{3} + \frac{2\pi R_2}{3}\right) I_d}{\left(\sqrt{3}\, mV_s - X_2 I_d\right)} \ (1.17)$$

On voit qu’en charge, g dépend essentiellement de α.
Si $I_d = 0$ c'est-à-dire que le moteur est à vide, $g = g_0$ donné précédemment par

$$g = g_0 = -\frac{K_T}{m} cos\alpha \quad (1.18)$$

The slip is always positive g> 0, that is to say that the machine operates as a motor, hence the name hyposynchronous cascade.

I.2.4 Equations of the hyposynchronous cascade

$$V_{C1} = \frac{3\sqrt{3}\, mgV_s}{\pi} \qquad (1.19)$$

ISSN No:-2456-2165

$$V_{C2} = \frac{3\sqrt{3}\,K_T V_s cos\alpha}{\pi} \quad (1.20)$$

$$R_C = 2(R_2 + R_T) \quad (1.21)$$

$$R_\mu = \frac{3(gX_2 + X_T)}{\pi} \quad (1.22)$$

II. HYPOSYNCHRONOUS CASCADE EQUATIONS

II.1 Dynamic equations

$$V_{C1} + V_{C2} = (R_C + R_\mu + pL_f)I_d \quad (2.1)$$

$$C_e - C_r = -j_P \Omega_s g \quad (2.2)$$

The detailed expression of the electromechanical couple for the operation of the hyposynchronous cascade,

$$C_e = \frac{U_d I_d}{\Omega_s g} \quad (2.3)$$

$$C_e = \frac{\left(\frac{3\sqrt{3}\,K_T V_s cos\alpha}{\pi} + \left(2R_T + \frac{3X_T}{\pi}\right) I_d\right) I_d}{\Omega_s g} \quad (2.4)$$

$$C_e = \frac{\left(-\frac{3\sqrt{3}\,mgV_s}{\pi} + \left(2R_T + \frac{3X_T}{\pi}\right) I_d\right) I_d}{\Omega_s g} \quad (2.5)$$

Avec :

$$C_e = \frac{3\sqrt{3}\,mV_s}{\Omega_s \pi} I_d = A.I_d \quad (2.6)$$

The variation of the torque of the asynchronous hyposynchronous cascade machine is similar to that of the direct current machine.

$$I_d = \frac{3\sqrt{6}V_s(mg + K_T cos\alpha)}{2(R_2 + R_T) + \frac{3}{\pi}(gX_2 + X_T)} \quad (2.7)$$

$$I_d == \frac{A_g + GU_c}{R_{cas} + R'_{cas}} \quad (2.8)$$

With:

$$R_2 = R_r + gm^2 R_s \quad (2.9)$$

$$R_{cas} = 2(R_r + R_T) + \frac{3}{\pi} X_T \quad (2.10)$$

$$R'_{cas} = 2m^2 R_s + \frac{3}{\pi} X_2 \quad (2.11)$$

$$G = \frac{\frac{3\sqrt{6}}{\pi} K_T V_S}{U_h} \quad (2.12)$$

The variation of the inverter control is of the arcosine form

II.2 Etude de la régulation

Let the operating point M (I_{d0}, U_{cm0}, g_0).
We introduce the differences:

$$\Delta I_d = I_d - I_{d0} \quad (2.13)$$

$$\Delta U_{cm} = U_{cm} - U_{cm0} \quad (2.14)$$

$$\Delta g = g - g_0 \quad (2.15)$$

Let us calculate the derivative of I_d:

$$\Delta I_d = \left(\frac{\partial I_d}{\partial U_{cm}}\right) \Delta U_{cm} + \left(\frac{\partial I_d}{\partial g}\right) \Delta g \quad (2.16)$$

Or :

$$\begin{cases} \frac{\partial I_d}{\partial U_{cm}} = \frac{G}{R_{cas} + gR'_{cas}} \\ \frac{\partial I_d}{\partial g} = \frac{A(R_{cas} + gR'_{cas}) - R'_{cas}(Ag + GU_{cm})}{(R_{cas} + gR'_{cas})^2} \end{cases} \quad (2.17)$$

$$\begin{cases} \frac{\partial I_d}{\partial U_{cm}} = K_M \\ \frac{\partial I_d}{\partial g} = \frac{A - I_d R'_{cas}}{R_{cas} + gR'_{cas}} \end{cases} \quad (2.18)$$

Posing:

$$K_R = \frac{R'_{cas}}{R_{cas} + gR'_{cas}} \quad (2.19)$$

Which means :

$$\frac{\partial I_d}{\partial g} = \frac{A - I_d R'_{cas}}{R_{cas} + gR'_{cas}} \quad (2.20)$$

$$\frac{\partial I_d}{\partial g} = \frac{A}{R_{cas} + gR'_{cas}} - I_{d0} K_R \quad (2.21)$$

So the general derivative of I_d is:

$$\Delta I_d = K_M \Delta U_{cm} + \left(\frac{A}{R_{cas} + gR'_{cas}} - I_d K_R\right) \Delta g \quad (2.22)$$

With:

$$\Delta g = \frac{\Delta\Omega}{\Omega_s} \quad (2.23)$$

The equation becomes:

$$\Delta I_d = K_M \Delta U_{cm} - \left(\frac{A}{R_{cas} + gR'_{cas}} - I_d K_R\right) \frac{\Delta\Omega}{\Omega_s} \quad (2.24)$$

The dynamic equation of the machine is:

$$\begin{cases} J\frac{d\Omega}{dt} = C - C_r - C_f \\ C_f = f\Omega \end{cases} \quad (2.25)$$

The two equations give us:

$$J\frac{d\Omega}{dt} = C - C_r - C_f \qquad (2.26)$$

$$(J_p + f)\Omega = C_e - C_r \qquad (2.27)$$

$$\Omega = \frac{C_e - C_r}{f(1 + pT_m)} \qquad (2.28)$$

$$T_m = \frac{J}{f} \qquad (2.29)$$

$$\Delta\Omega = \frac{\Delta C_e - \Delta C_r}{(1 + pT_m)} = \frac{\frac{A}{\Omega_s} I_d - \Delta C_r}{(1 + pT_m)} \qquad (2.30)$$

Where f is the coefficient of friction. From the dynamic equation we get:

$$\Delta I_d = K_M \Delta U_{cm} - \left(\frac{A}{R_{g0} + pL_f} - I_{d0} K_R\right)\frac{\Delta\Omega}{\Omega_s} \qquad (2.31)$$

$$R_{g0} = R_{cas} + gR'_{cas} \qquad (2.32)$$

$$T_e = \frac{L}{R_{g0}} \qquad (2.33)$$

$$\Delta I_d = K_M \Delta U_{cm} - \left(\frac{A}{\frac{R_{g0}}{1 + pT_e}} - I_{d0} K_R\right)\frac{\Delta\Omega}{\Omega_s} \qquad (2.34)$$

From equation (3.55), we obtain the following equation:

$$\Delta I_d = K_M \Delta U_{cm} - \frac{A}{\frac{R_{g0}}{1 + pT_e}}\frac{\Delta\Omega}{\Omega_s} + I_{d0} K_R \frac{\Delta\Omega}{\Omega_s} \qquad (3.35)$$

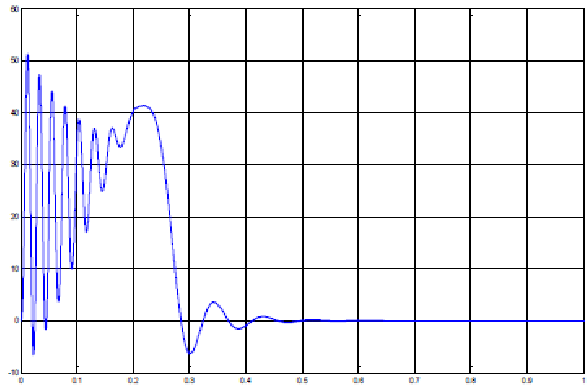
III. MODELS OF CONTROL BY THE PARAMETERS OF MAS DE LA BRALIMA

III.1 Parameters of asynchronous motor 1

- Nominal power: 1.08 kW
- Nominal voltage: 220/380 V
- Nominal current: 2.05 / 4.91 A
- Number of pole pairs: 2
- Power factor: 0.8
- Rotation speed: 1500 rpm
- Stator resistance: 10 Ω
- Rotor resistance: 6.3 Ω
- Cyclic stator inductance: 0.4642 H
- Cyclic rotor inductance: 0.4612 H
- Mutual inductance: 0.4212H
- Moment of inertia of the rotor: 0.02 kg.m²
- Rated resistive torque: 5 N.m

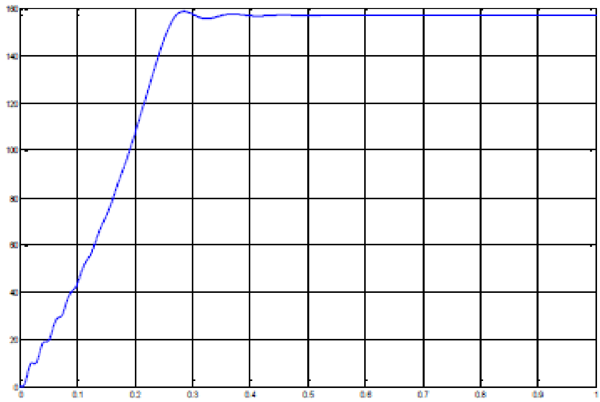
III.2 Engine simulation

III.2.1 No-load starting torque response (Nm)



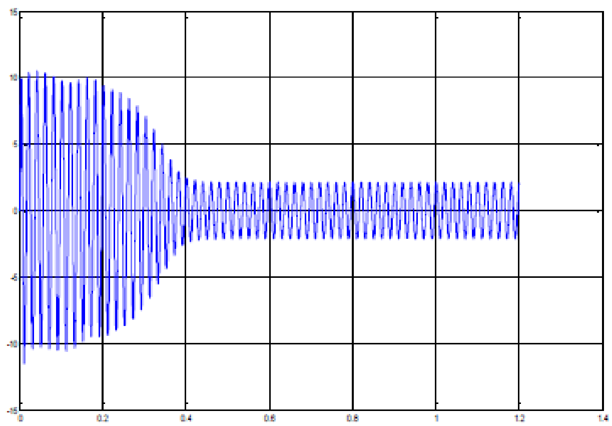
Figures III.1: No-load starting torque response (Nm)

III.2.2 No-load start speed response (rd / min)



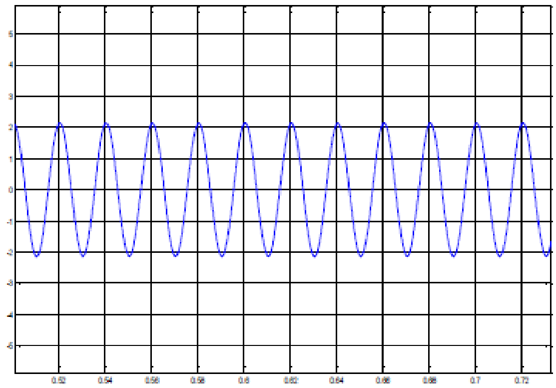
Figures III.2: No-load speed response (rd / min)

III.2.3 No-load start response of stator current (A)



Figures III.3: No-load start stator current response (A)

III.2.4 No-load starting response of the stator current in steady state (A)

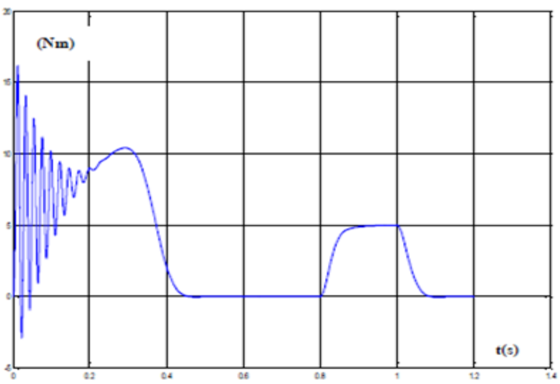


Figures III.4: No-load starting response of the stator current in steady state (A)

III.3 Direct starting of the asynchronous machine with a load

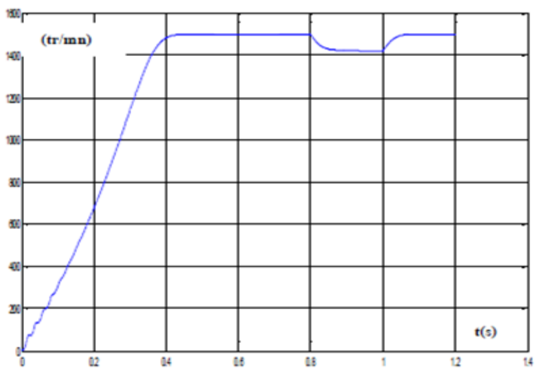
At the instant t = 0.8s load the machine with a resistive torque of 5 Nm up to t = 1s.

III.3.1 Torque response (Nm)



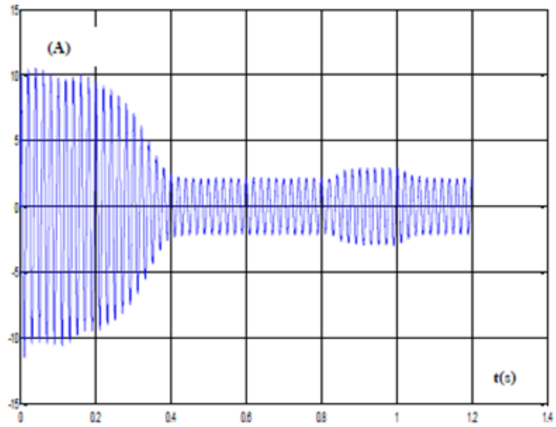
Figures III.5: Direct starting of the asynchronous machine with a load Torque response (Nm)

III.3.2 Speed response (rpm)



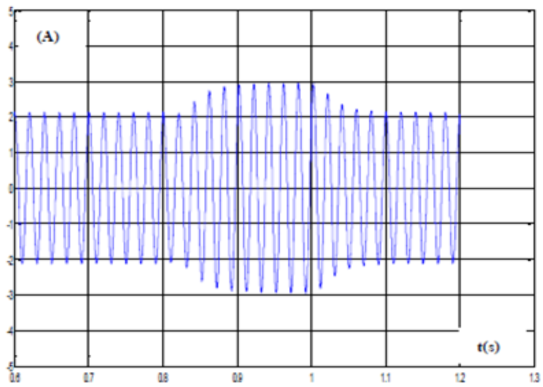
Figures III.6: Direct starting of the asynchronous machine with a load Speed response (rpm)

III.3.3 Response of the stator current (A)



Figures III.7: Direct starting of the asynchronous machine with a load Response stator current (A).

III.3.4 Stator current response in steady state (A)



Figures III.8: Direct starting of the asynchronous machine with a load Response of the stator current in steady state (A)

IV. IDENTIFICATION OF MAS PARAMETERS

IV.1 Offline method

The identification of the MAS parameters based on the use of an equivalent circuit (T-circuit, figure 4.1) of the phases of the machine presented in the standard, this method based on the principle of off-line identification, is carried out from two experimental measurements:

1. Short-circuit test (locked rotor) or load test at synchronism speed
2. Synchronous speed test (no-load test)

By adding a DC measurement of the resistance of the stator windings to determine equivalent circuit parameters.

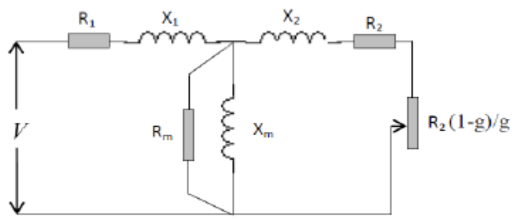


Figure.IV.1. Diagram of the equivalent circuit of a phase

ISSN No:-2456-2165

IV.2 Identification of the resistance of the stator windings Rs

The identification of the stator resistance of the cage MAS is carried out hot by a volt-ampere-metric method, figure. IV.2, continuously, and the voltage and the current are measured (without exceeding In) using two multimeters capable of accurately indicating the voltage and current applied to the terminals of the stator windings of the star-connected motor.

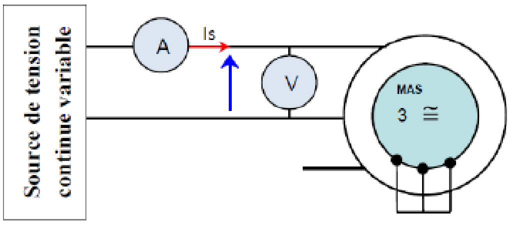


Figure.IV.2. Voltammetric method

Assuming that the resistance of each phase is the same, the resistance of one phase is equal to half of the ratio between the voltage and the current observed at the terminals of two phases. R=E/2I

IV.3. No-load tests: Determination of L_s and R_f

IV.3.1 Two-wattmeter method By taking a series of measurements for different values

When empty, the engine does not generate a load. In this operation, the rotor turns practically at synchronism g = 0.

The MAS is supplied with an adjustable voltage and normal frequency, with the motor running without load, the power is measured by the method of two wattmeters [Jas, 05], one connected between phase U and W and the other connected between phase V and W, the total power absorbed is the sum of the two powers indicated by the two wattmeters (neutral is not connected). Take the following points into consideration when performing the measurements: 0 sP

- The supply voltage can hardly drop below a quarter of the nominal value of U, otherwise the speed would begin to decrease appreciably and we would no longer have the constant mechanical losses.
- To avoid accidental errors, the supply voltage is varied within certain limits, generally from 0.5 Un to 1.5 Un

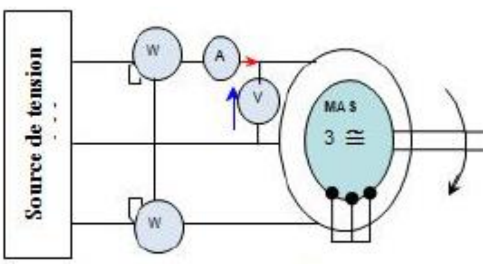


Figure IV.3: Simplified electrical diagram

IV.3.2 Approximate equivalent circuit for the no-load test becomes

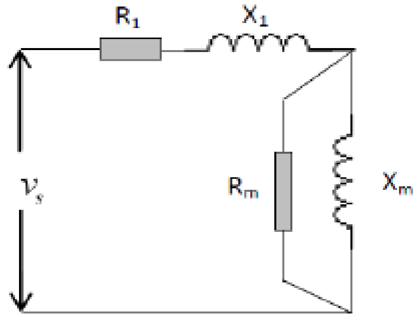


Figure IV.4: Approximate equivalent circuit for the no-load test becomes.

The asynchronous motor absorbs a power P_{s0} which corresponds to the sum of mechanical, ferromagnetic (fer) and Joule losses at the stator.

$$P_{s0} = P_{mec} + P_{fer} + P_{js}$$

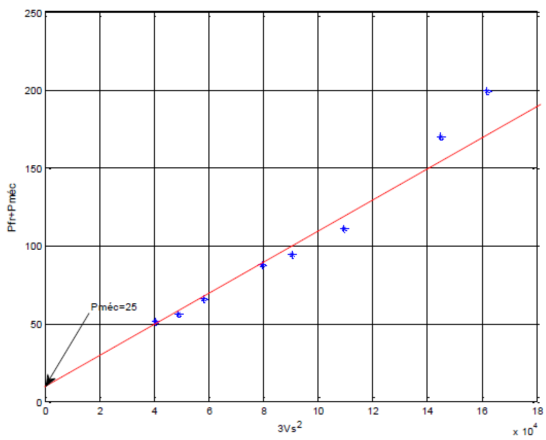


Figure IV.5 : Loss separation method.

V. CONCLUSION

We have seen that this article consisted in modeling the control of the industrial ring motor. The models of the control used in synchronous cascade translate the equations of the variations in speed beyond the limit of the synchronous. We applied these models on the industrial engine of the Bralima and simulated in simulink under the Matlab environment.

This article to present calculation models allowing to vary the speed of rotation of the industrial motor below or beyond the speed of synchronism. When starting the machine, the torque is 8 times greater than the nominal torque and the same is true for stator and rotor current, which is due to the motor's need to overcome the inertia of the motor and the load. After the transient regime, the torque stabilizes at the value of the load torque, which allows the stator and rotor currents to stabilize at the values corresponding to the load torque.

ISSN No:-2456-2165

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Mbengayi Kabamukoyi, Diploma from Master's degree 2016 University of Brazzaville-Congo and PhD student in engineering sciences of The University of Brazzaville-Congo

Dr. Ir Lidinga Mobonda Flory, PhD In Engineering Sciences, Dept. Of Electricity. Electrical and Elctronic Ingineering Research Laboratory ENSP-UMNG. Speciality : Automatic Energy Systems and Digital Method of Industrial Operations. National President of the National Network of Engineers of Congo (RNIC).

Haroun Abba Labane, PhD in engineering sciences of The University of Brazzaville-Congo. Electrical and Elctronic Ingineering Research Laboratory ENSP-UMNG

Rodrigue Armel Patrick Okemba PhD in engineering sciences of The University of Brazzaville-Congo. Electrical and Elctronic Ingineering Research Laboratory ENSP-UMNG

Prof.Dr.Ir André Bandekela Kazadi, Ph.D is an electrical engineer, he received his PhD, from the institute energétique of Moecou (Rusie). He is presently lecturer at the ISTA-Kinshasa of Congo, Dept. of electricity.