

Modeling of a variable Speed control system of the Industrial drive chain of Carrigres-Kinshasa by Pulse Width Modulation

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Abstract

In this article, we will study static converters, their operation, and the behavior of the voltages and currents that are necessary. Once the modeling of the asynchronous machine is completed, and the control of the asynchronous drive has been studied, namely pulse width modulation, the effectiveness of the adopted technique can only be confirmed after supplying the machine with the voltages delivered by the inverter, and this for two tests, no-load and load.

Keywords: Modeling, Control System, Variable Speed, Industrial Drive Chain Pulse Width Modulation.

Introduction

The conversion of electrical energy into a suitable form after its production requires special circuits called static converters^{1,2}. An inverter is a static converter that allows a load to be supplied with alternating current from a direct current source; it is a DC-AC converter^{3,4}. The inverter is said to be autonomous when it imposes its own frequency on the load. If the DC source is a voltage source, the inverter is called a voltage inverter^{5,6}. It imposes the voltage waveform across the load, while the current waveform depends on the load. If the DC source is a power source, the inverter is called a power converter. It imposes the current waveform, while the voltage waveform at the terminals of the load depends on the nature of the load^{7,8}.

Convenient configuration with pulse width modulation (PWM):

An inverter is a static converter capable of converting electrical energy from a DC voltage source to an AC current. Inverters have a wide range of applications in the industry, such as variable speed drives for three-phase motors, backup power supplies and more^{9,10}. Thanks to technological advances in semiconductors and the emergence of new control technologies, inverters have become more efficient^{11,12}.

Inverter Modeling: To model the voltage inverter, we consider its power supply as a perfect source (DC bus), assumed to consist of two generators of equal $U_{dc}/2$ emf connected by each other by a point denoted n_0 .

Model of equations

Fourier Series Development: The voltage is an odd square wave function with a zero mean value. Its $u(t)$ Fourier series

decomposition contains no cosine terms and does not exhibit even-order harmonics.

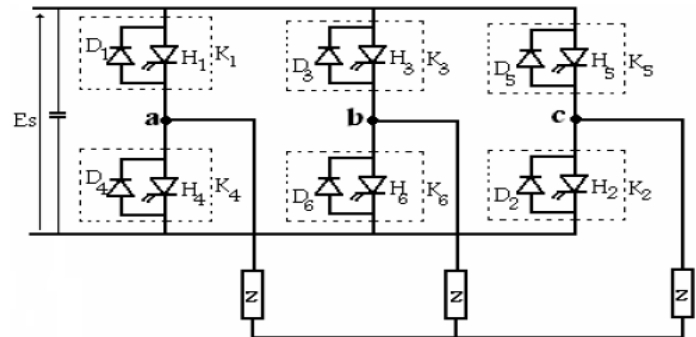


Figure-1: Practical setup for pulse width modulation (PWM).

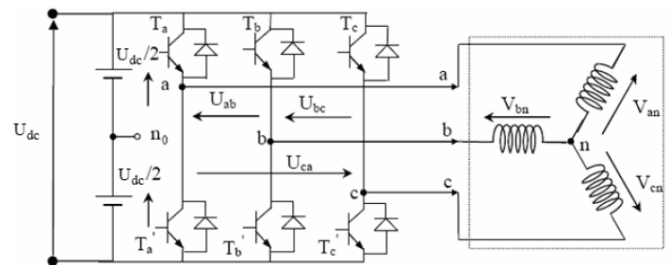


Figure-2: Diagram of the two-level three-phase inverter.

$$u(t) = \sum_{k=0}^{\infty} \frac{4E_s}{(2K+1)\pi} \sin(2K+1)\omega t \quad (1)$$

Full-wave control: There are six sequences per period. Each electronic switch K_i is closed for half a period (180° control). The conduction (control) sequences are: (K_5, K_6, K_1) ; (K_6, K_1, K_2) ; (K_1, K_2, K_3) ; (K_2, K_3, K_1) ; (K_3, K_4, K_5) ; (K_4, K_5, K_6) . Generally, the diodes (called recovery diodes) are used to return

the negative current from the load to the source. The capacitor C inserted at the source input filters the voltage E_s and provides reactive power for establishing flux in the machine's air gap. In the balanced system:

$$\begin{cases} v_a + v_b + v_c = 0 \\ i_a + i_b + i_c = 0 \end{cases} \quad (2)$$

$$\begin{cases} U_{ab} = v_a - v_b \\ U_{ac} = v_a - v_c \end{cases} \quad (3)$$

From equations (2.2) and (2.3), we obtain:

$$\begin{cases} v_a = \frac{U_{ab} + U_{ac}}{3} \\ v_b = \frac{U_{bc} + U_{ba}}{3} \\ v_c = \frac{U_{ca} + U_{cb}}{3} \end{cases} \quad (4)$$

PWM Command: It is very useful for controlling the asynchronous motor, based on the comparison between two signals, the first is triangular and the second is sinusoidal, we generate the pulse sequences. For this control strategy and for a frequency of $f = 50$ Hz, we define the amplitude ratio and the frequency ratio.

$$r = \frac{U_c}{U_m} \quad (5)$$

$$m = \frac{f_c}{f_m} \quad (6)$$

Control State Equation: The motor was modeled based on the voltages that we denote V_{an}, V_{bn} . The inverter is controlled by logic quantities S_i . We call T_i the T_i transistors (assumed to be ideal switches) and have: V_{cn} i. If $S_i = 1$, then T_i is passing and T_i is open, ii. If $S_i = 0$, then T_i is open and T_i is passing.

The line-to-line voltages are obtained from the inverter outputs:

$$\begin{cases} U_{ab} = V_{an0} - V_{bn0} \\ U_{bc} = V_{bn0} - V_{cn0} \\ U_{ca} = V_{cn0} - V_{an0} \end{cases} \quad (7)$$

The phase voltages of the load resulting from the line voltages have a sum of zero, therefore:

$$\begin{cases} V_{an} = \left(\frac{1}{3}\right) [U_{ab} - U_{ac}] \\ V_{bn} = \left(\frac{1}{3}\right) [-U_{bc} - U_{ab}] \\ V_{cn} = \left(\frac{1}{3}\right) [-U_{ca} - U_{bc}] \end{cases} \quad (8)$$

Starting from the inverter output voltages, by introducing the neutral voltage of the load relative to the reference point n_0

$$\begin{cases} V_{an0} = V_{an} + V_{nn0} \\ V_{bn0} = V_{bn} + V_{nn0} \\ V_{cn0} = V_{cn} + V_{nn0} \end{cases} \quad (9)$$

Therefore, we can deduce that:

$$V_{nn0} = \frac{1}{3} [V_{an0} + V_{bn0} + V_{cn0}] \quad (10)$$

The state of the switches, assumed to be perfect, $\Leftrightarrow S_i (i = a, b, c)$ is:

$$V_{in0} = S_i \cdot U_{dc} - \frac{U_{dc}}{2} = (S_i - 0,5)U_{dc} \quad (11)$$

Therefore, we have:

$$\begin{cases} V_{an0} = (S_a - 0,5)U_{dc} \\ V_{bn0} = (S_b - 0,5)U_{dc} \\ V_{cn0} = (S_c - 0,5)U_{dc} \end{cases} \quad (12)$$

Substituting equation (2.11) into equation (2.12), we obtain:

$$\begin{cases} V_{an} = \frac{2}{3}V_{an0} - \frac{1}{3}V_{bn0} - \frac{1}{3}V_{cn0} \\ V_{bn} = -\frac{1}{3}V_{an0} - \frac{2}{3}V_{bn0} - \frac{1}{3}V_{cn0} \\ V_{cn} = -\frac{1}{3}V_{an0} - \frac{1}{3}V_{bn0} + \frac{2}{3}V_{cn0} \end{cases} \quad (13)$$

Substituting equation (2.12) into equation (2.13), we obtain:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{1}{3} \cdot U_{dc} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \quad (14)$$

Simply applying Park's transformation is enough to go from a three-phase system to a two-phase system.

Control by sinus-triangle modulation: Sinusoidal-triangle PWM (Pulse Width Modulation) is achieved by comparing a low-frequency modulating wave (reference voltage) to a high-frequency triangular carrier wave. The switching instants are determined by the points of intersection between the carrier and modulating waves. The switching frequency of the switches is fixed by the carrier wave. Sinusoidal reference voltages are expressed as:

$$\begin{cases} V_{ref a} = V_m \sin(2\pi ft) \\ V_{ref b} = V_m \sin(2\pi ft - \frac{2\pi}{3}) \\ V_{ref c} = V_m \sin(2\pi ft + \frac{2\pi}{3}) \end{cases} \quad (15)$$

The carrier equation is given by:

$$V_p(t) = \begin{cases} V_{pm} [4(\frac{t}{T_p}) - 1] & \text{si } 0 \leq t \leq T_p/2 \\ V_{pm} [-4(\frac{t}{T_p}) + 3] & \text{si } T_p/2 \leq t \leq T_p \end{cases} \quad (16)$$

Fourier Series Decomposition: If f is a periodic function with period T , and is integrable, we can decompose it into a Fourier series as follows:

$$f(x) = a_0 + \sum_{k=1}^{\infty} (a_k \cos kx + b_k \sin kx) \quad (17)$$

Such as:

$$a_0 = \frac{1}{2T} \int_{-T}^{+T} f(x) dx \quad (18) \quad f(x) = a_0 + \sum_{k=1}^{\infty} A_k \sin(kx + \varphi_k) \quad (21)$$

Or:

$$a_k = \frac{1}{2T} \int_{-T}^{+T} f(x) \cos kx dx \quad (19) \quad A_k = \sqrt{\frac{a_k^2 + b_k^2}{2}} \quad (22)$$

$$b_k = \frac{1}{2T} \int_{-T}^{+T} f(x) \sin kx dx \quad (20) \quad \varphi_k = \text{artg} \left(\frac{b_k}{a_k} \right) \quad (23)$$

The function f can also be written differently:

Simulation of the asynchronous inverter machine association

No-load operation

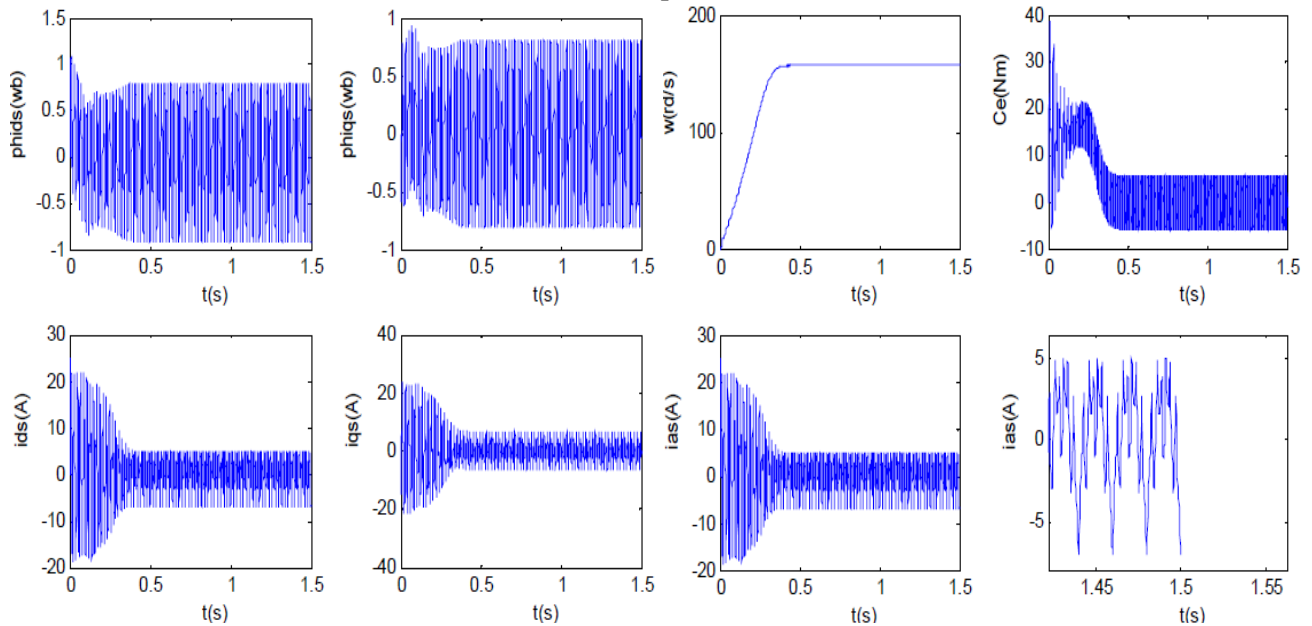


Figure-3: Vacuum machine inverter association for m=6.

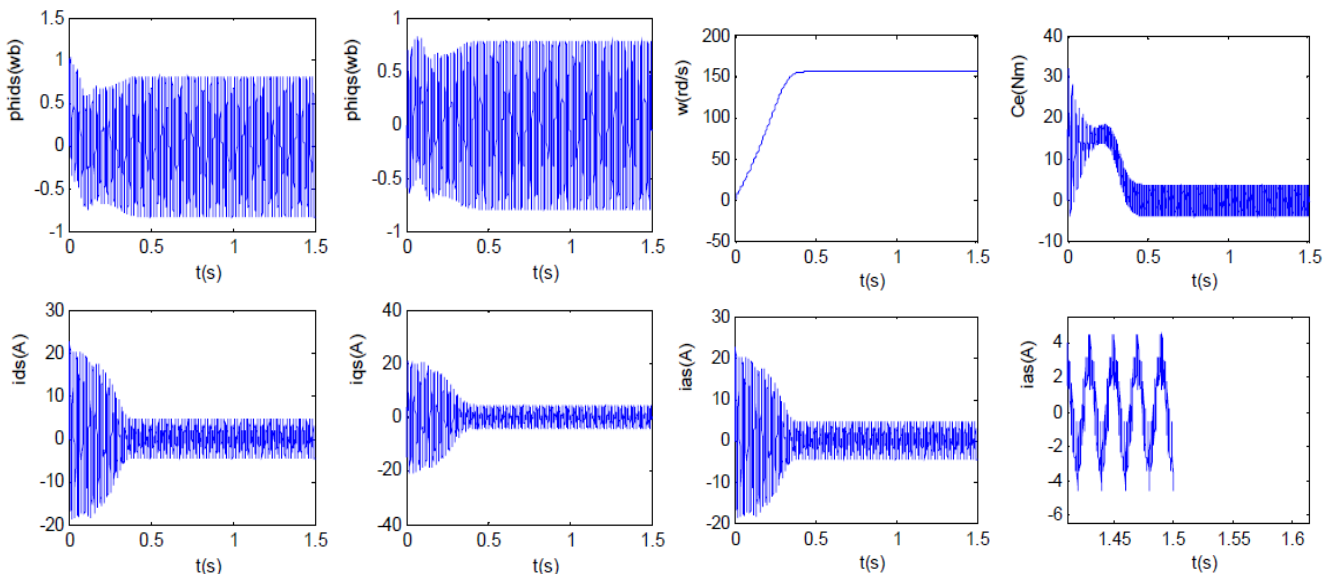


Figure-4: Vacuum machine inverter association for m=12

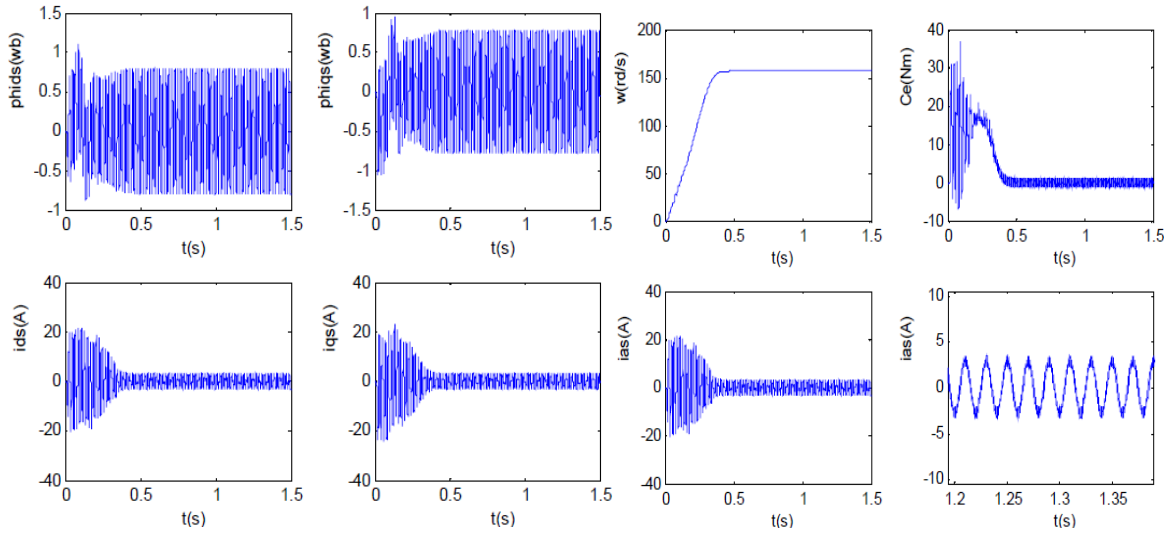


Figure-5: Vacuum machine inverter association for m=36.

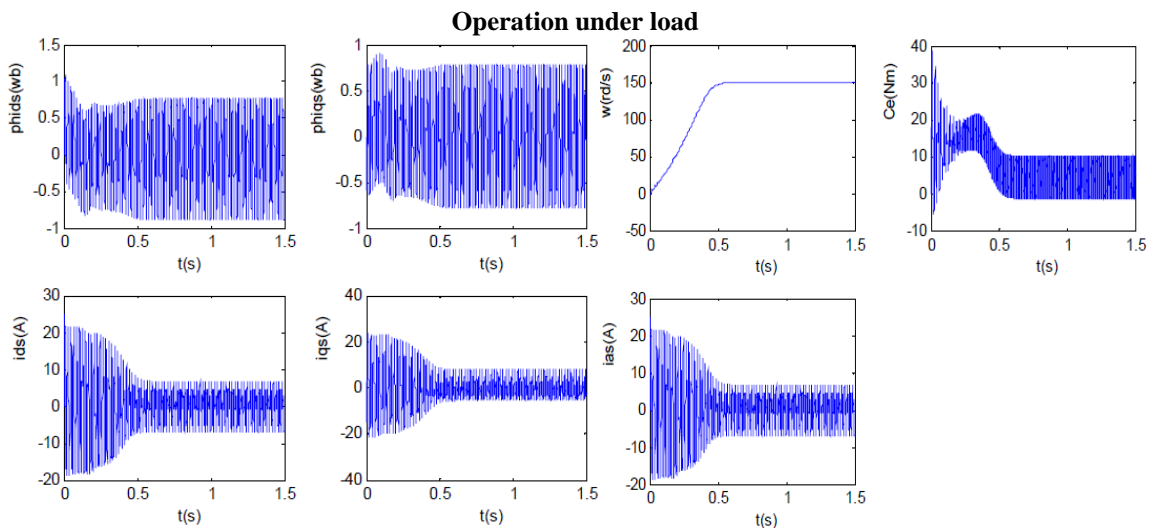


Figure-6: Inverter-machine association under load for m=6.

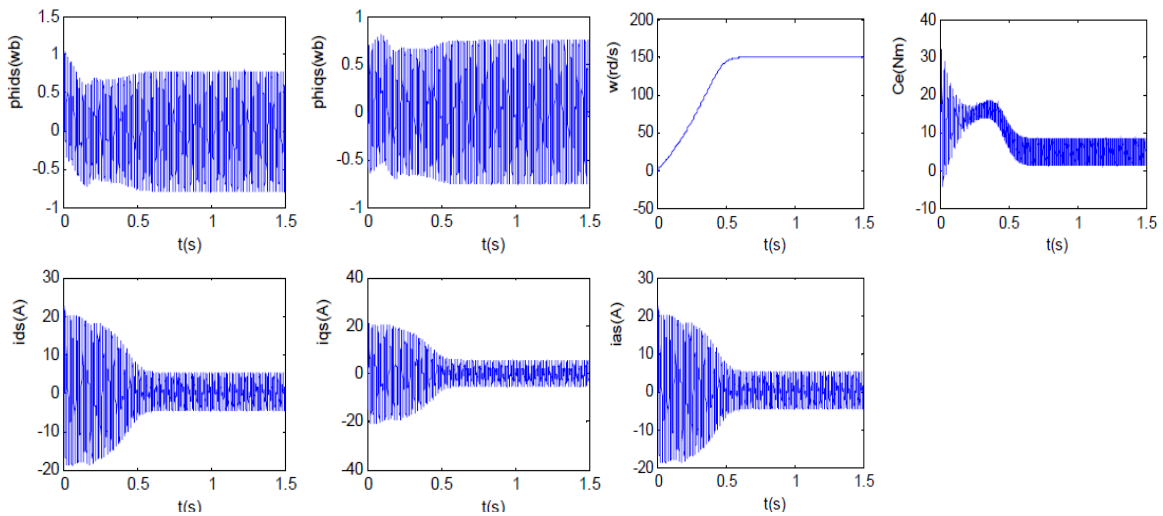


Figure-7: Inverter-machine association under load for m=12

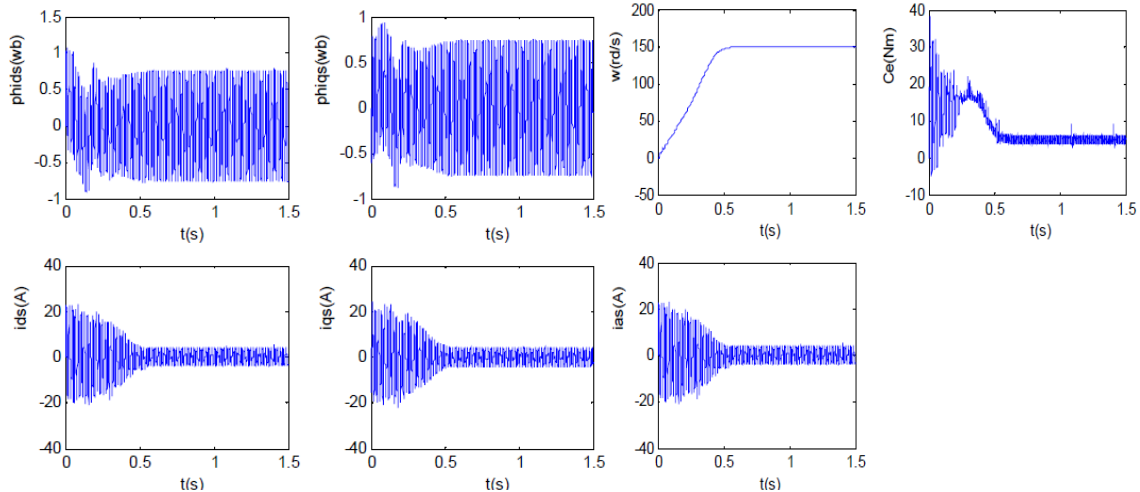


Figure-8: Inverter-machine association under load for $m=36$.

Interpretation of simulation results

By combining the asynchronous machine with the PWM control inverter, and for two tests, no-load and load, we notice that as m increases, there is a significant reduction in pulsating torques, which are directly related to harmonics. At $m = 36$, the torque control is significantly better, and the steady-state speed oscillations are practically non-existent. For the load test, we note a decrease in speed and a longer transient regime since the start-up takes place under load.

Conclusion

In this article, we presented the modeling of an asynchronous motor powered by a balanced, three-phase sinusoidal voltage source at a constant frequency, established under simplifying assumptions. Finally, we studied the asynchronous machine associated with a full-wave voltage inverter (controlled at 180° and 120°) and a PWM inverter. The voltages delivered by the inverter were presented in detail in the manuscript. The simulation results show that supplying the asynchronous machine with a triangular-carrier pulse-width modulation (PWM) inverter under no-load or load conditions is quite satisfactory, as can be seen in the speed characteristic where the ripples are negligible in steady state, as well as the pulsating torques, which can be reduced by increasing the modulation index m , as shown in the torque characteristic.

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