Efficient Control Of A Three Induction Motor Driving A Craft Mill Of Millet

Moustapha Diop, Lamine Thiaw, Mouhamadou Thiam, Moctar Mbodji, Nogoye DIAW

Abstract: This paper presents an efficient control strategy of a grinding device of millet. The grinding device is constituted of an inverter and a craft mill with induction motor. The control strategy of this grinding device is based on the scalar control (V/f) for the craft mill and the Space Vector Modulation (SVM) for the three-phase inverter. The implementation of the control strategy by simulation in Matlab-Simulink gave satisfactory results in reducing efficiently the starting current while maintaining the performance of the grinding system.

Index Terms: Craft mill of millet, Induction motor, Inverter, Scalar control, SVM, Flow.

1 INTRODUCTION

The millet is the staple food in many West African countries. The transformation of the millet is one of the most important issues in rural areas characterized by the absence of the electricity network. The transformation of millet was done traditionally by women, with the mortar and pestle. This traditional method is laborious, painful and with a very low hourly production. She was slightly mechanized by the introduction of small transformation units. In the process of mechanization of transformation, most of the mills used in urban and rural areas were imported and often operate with DC motors. In rural areas, most transformation units are powered by diesel generators. These are faced to problems to the continuous supply of diesel generators and the cost of the mill and the DC motor. To solve the problems of the high cost of imported mills and cost of DC motors, the craft mill of millet is now used in most transformation units. The choice of craft mill of millet and induction motor squirrel cage less expensive and more robust [1] [2], is due to the low purchase price with less maintenance and the availability of equipment in the whole country [3]. With the implementation of rural Electrification projects through the use of renewable energy, the rural areas have energy sources based on solar photovoltaic. With these energy sources and availability of mills in the whole territory, helped to set up new transformation units in rural areas. For the establishment of transformation systems, with these solar sources and craft mill, a three-phase inverter with the SVM control is used. Despite the use of this control to improve the voltage waveform, the major problem in these motorized systems is the starting current.

- *Moustapha DIOP is researcher at Laboratory of Renewable Energy (Senegal) and Laboratory of Electrical Systems (Tunisia), PhD candidate*
- *Lamine Thiaw is working at the department of electrical genie of Polytechnic Higher School. Researcher and chief of Laboratory of Renewable Energy, University Cheikh Anta Diop, Senegal.*
- *Mouhamadou THIAM is lecturer at Polytechnic School of Thiès and Researcher of Laboratory at Renewable Energy, Senegal.*
- *Nogoye DIAW and Moctar MBODJI are researchers and PhD candidate at Laboratory of Renewable Energy.*

To reduce the current at startup, the strategy scalar control V/f closed loop is used. The control strategy ensures a soft start of the craft mill. This paper is articulate on four points: The second point is devote to the methodology that addresses the modeling and the strategy of control. In the third point, the simulation results and discussions are presented. Finally, the conclusion is doing in the last point.

2 METHODOLOGY

Fig. 1 shows the device. It is consists of the grinding device, consisting of craft mill and the induction motor, and the three-phase inverter. To simulate the system, it's necessary to model the different parts that compose it.

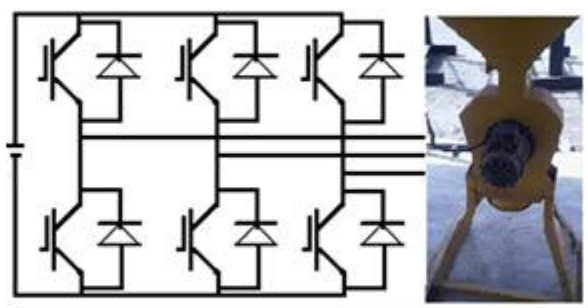

Fig. 1. *The device of grinding millet*

2.1 Modeling of inverter

The functionally of the inverter is based on the state of switches that compose it. The switching is assured by three logical functions (S_1, S_2, S_3). These functions have allowed to establish the relationship (Eq.1) between the voltages in the three phases (V_a, V_b, V_c) of the actuator of the mill of millet and the voltage of the DC source (V_{dc}).

$$\begin{bmatrix} V_a \\ V_b \\ V_b \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix} \quad (1)$$

2.2 Modeling of the grinding device

The modeling of induction motor is widely treat in the literature. The electrical, magnetic and mechanical equations, linked to the rotating field, applied to the Laplace transform of variable (p), have allowed to establish the relations giving the model of the motor in the system (d, q) given by the equation (2) [4].

$$\begin{cases} V_{sd} = (R_s + pL_s)i_{sd} - \omega_s L_s i_{sq} + sL_m i_{rd} - \omega_s L_m i_{rq} \\ V_{sd} = \omega_s L_s i_{sd} + (R_s + pL_s)i_{sq} + \omega_s L_m i_{rd} + sL_m i_{rq} \\ 0 = (R_r + pL_r)i_{rd} + sL_m i_{sd} - \omega_r L_m i_{sq} - \omega_r L_m i_{rq} \\ 0 = (R_r + pL_r)i_{rq} + \omega_r L_m i_{sd} + sL_m i_{sq} + \omega_r L_m i_{rd} \\ \Omega = \dfrac{C_m - C_r}{Jp - f_r} \;\; ; C_m = \dfrac{3}{2} P \dfrac{L_m}{L_r}(i_{sq}\phi_{rd} - i_{sd}\phi_{rq}) \end{cases} \tag{2}$$

Where:

$V_{sd}; i_{sd}; \phi_{sd}$: Direct components of the voltage, current and flux to the stator;

$V_{sq}; i_{sq}; \phi_{sq}$: Quadrature components of the voltage, current and flux to the stator;

$V_{rd}; i_{rd}; \phi_{rd}$: Direct components of the voltage, current and flux to the rotor;

$V_{rq}; i_{rq}; \phi_{rq}$: Quadrature components of the voltage, current and flux to the rotor;

ω_s, ω_r, J, P : Pulsations on the stator, electrical angular rotor speed, Moment of inertia and Number of poles;

L_s, L_r, L_m: Inductance of the stator, rotor and mutual;

R_s, R_r, f_r; Stator resistance, rotor resistance and coefficient of friction;

C_m, C_r, Ω: Electromagnetic torque, torque of the load and mechanical speed.

The mill of millet can be considered as a mechanical load for the motor. The model of the craft mill is defined by the load torque profile. The characteristic noted in the operation of the mills is that grinding is done in steady state. The parameters mechanical (speed and torque) of mill are function of the grain flow (D). According to their functioning principle the speed varies with flow so there is a relationship between speed and flow (Eq. 3).

$$\omega = \omega_0 - k \times D \tag{3}$$

Where ω, ω_0 , k are respectively speed in load, speed without load and parameters characteristic of the mill.

With the functioning principle of the craft mill and the hammers game that reduces the grain size, the shape of the torque can be written as a combination of four existing torque of load. Equation (4) gives the mechanical characteristic equation with the parameters (k_1, k_2, k_3, k_4) characteristics of the mill of millet.

$$Cr = k_1 + k_2\omega + k_3\omega^2 + k_4\omega^{-1} \tag{4}$$

For the mill used for this work, the parameters are determined by experimental tests. Table 1 give their values [5].

Table 1. *The values of parameters of the mill*

Parameters	Values
$k_1 (N.m)$	2091.5
$k_2 (N.m.s / rd)$	–12.031
$k_3 (N.m.s^2 / rd)$	0.0171
$k_4 (N.m.rd / s)$	0
$k (rd.kg)$	5.8161
$\omega_o (rd / s)$	313.47

Equations (3), (4) and Table 1 gives the torque of the mill according to the flow (Eq.5):

$$Cr = k_3(\omega_o - k \times D)^2 + k_2(\omega_o - k \times D) + k_1 \tag{5}$$

2.3 Control if device

The scalar control (V/f) with SVM strategy is used to control the system. Fig. 2 shows the system with its control.

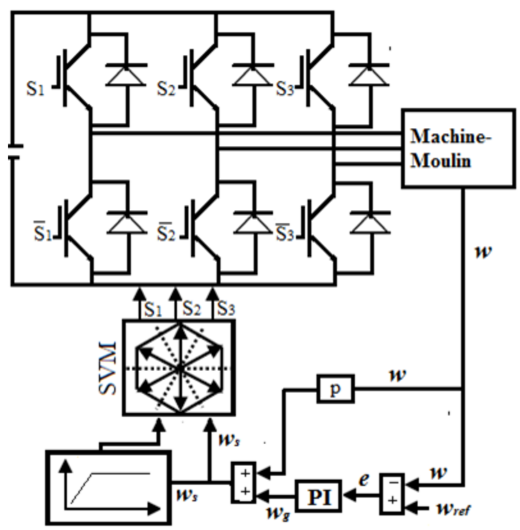

Fig. 2. *Schema of the device with the control strategy*

Scalar control:

The principle of scalar control is to maintain the V/f constant [6] [7]. Equation (6) gives the expression of the maximum torque.

$$C_{e\max} = \frac{3pL_m{}^2}{2L_s(L_r L_s - L_m{}^2)} \left(\frac{V_s - R_s I_S}{\omega_s} \right)^2 \tag{6}$$

The simplified expression, or the voltage drop across the stator resistance is neglected, is often used. However, at low speed, the voltage drop can not be neglected. We propose to compensate the drop by a threshold voltage (V_o) and operate at a limit frequency (f_o). Fig. 3 shows the profile of the voltage amplitude as a function of frequency.

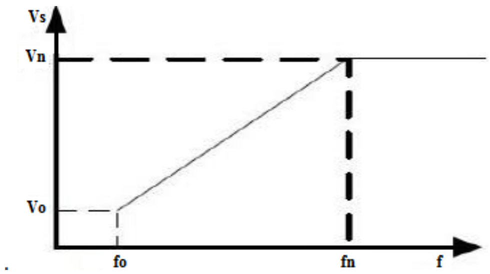

***Fig. 3.** Modified profile of control (V/f)*

The profile allowed to establish the relation (7) giving the voltage amplitude (V_s) and the frequency (f) from the nominal values of the voltage (V_n) and frequency (f_n).

$$V_s = \frac{V_n - V_o}{f_n - f_0}(f_n - f) + V_0 \qquad (7)$$

For controlling the system, the closed-loop strategy is used. It uses a loop who, from the error of the speed of the mill (ω), increases the frequency of the stator voltages to correct the error in speed due to the slip (ω_g). Equation (8) give the generated stator pulsation (ω_s).

$$\omega_s = \omega_g + \omega \qquad (8)$$

The three voltages (*i=1, 2, 3)*, generated from the frequency, are given by equation (9).

$$V_i = \left(\frac{V_n - V_o}{f_n - f_0}(f_n - f) + V_0\right)\sin\left(2\pi f t - 2\frac{(i-1)}{3}\pi\right) \qquad (9)$$

The voltages (V_i) and pulsation (ω_s) generated are the input variables of the SVM control.

SVM control:

It processes the signals in the diphase system (α, β). The three generated tensions have established the components (V_α, V_β) of the reference vector (U_s) in the system (α, β). The components of voltage in the system (α, β) are given by the relation (10)

$$V_\beta = -\sqrt{\frac{3}{2}}V_s\cos(\omega t) \qquad V_\alpha = \sqrt{\frac{3}{2}}V_s\sin(\omega t) \qquad (10)$$

The principle is to rebuild the vector (Us) from the eight voltage vectors corresponding to states of the inverter and the 6 sectors [8]. Fig. 4 shows the states, defined by the eight vectors, the sectors and the reference (Us).

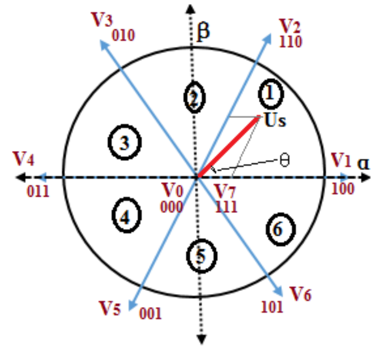

***Fig. 4.** Schematic diagram of SVM control*

The strategy SVM offer a calculation of switching times according to the position of the vector (U_s) and the sector (n). The application of times (T_1 and T_2) on the adjacent vectors, the relation (14) gives expression (U_s).

$$\vec{U}_s = \frac{T_1}{T_s}\vec{U}_1 + \frac{T_2}{T_s}\vec{U}_2 + \frac{T_0}{T_s}\vec{U}_0 + \frac{T_7}{T_s}\vec{U}_7 \qquad (11)$$

Fig.4 and the symmetric modulation have allowed to establish the relationship (12). She gives the expressions of T_1, T_2, the time applied to the zero vectors V_o and V_7 (T_d) in the different sectors and the time modulation (T_s).

$$\begin{cases} T_1 = \sqrt{3}T_s m\sin(n\,\pi/3 - \theta) \\ T_2 = \sqrt{3}T_s m\sin(\theta - (n-1)\,\pi/3) \\ T_S = T_1 + T_2 + T_0 + T_7 \\ T_7 = T_0 = (T_s - T_1 - T_2)/2 = T_d/2 \end{cases} \qquad (12)$$

The switching times are used to generate the sequence of logic function (S_1, S_2, S_3) in the six sectors, shown in table 2.

***Table 2 :** Sequence of logic functions on the different sectors*

Sector 1	Sector 2	Sector 3
$S_1 = T_1 + T_2 + T_d/2$ $S_2 = T_2 + T_d/2$ $S_3 = T_d/2$	$S_1 = T_1 + T_d/2$ $S_2 = T_1 + T_2 + T_d/2$ $S_3 = T_d/2$	$S_1 = T_d/2$ $S_2 = T_1 + T_2 + T_d/2$ $S_3 = T_2 + T_d/2$
Sector 4	**Sector 5**	**Sector 6**
$S_1 = T_d/2$ $S_2 = T_1 + T_d/2$ $S_3 = T_1 + T_2 + T_d/2$	$S_1 = T_2 + T_d/2$ $S_2 = T_d/2$ $S_3 = T_1 + T_2 + T_d/2$	$S_1 = T_1 + T_2 + T_d/2$ $S_2 = T_d/2$ $S_2 = T_1 + T_d/2$

3 Results and discussion

Implementation of the model and strategy control in Matlab/Simulink have allowed to simulate the system. The results were obtained by the simulation of model with the parameters given in appendix.

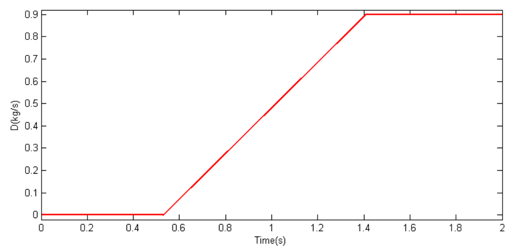

Fig. 5. *Profile of the millet flow*

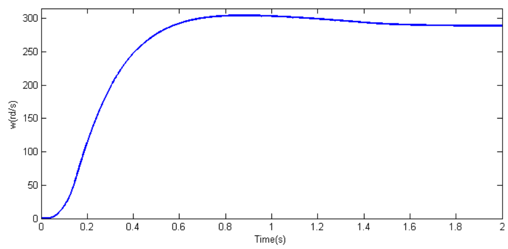

Fig. 6. *Speed of mill*

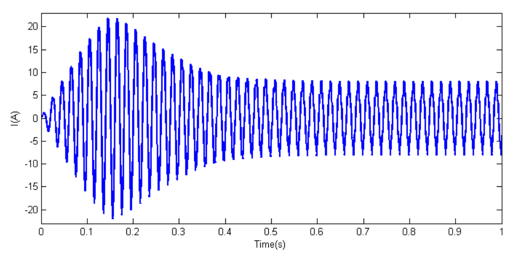

Fig. 7. *Current in one phase of the stator*

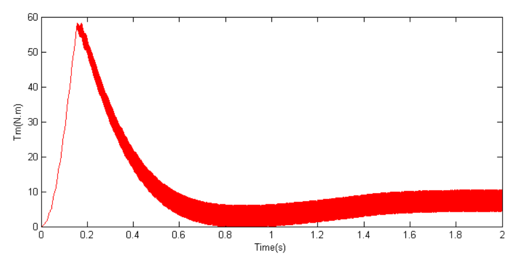

Fig. 8. *Electromagnetic torque*

The simulation is made by applying a load torque profile, translated by the flow of the millet, quasi-linear during the loading phase (Fig. 5). The results show that increasing the flow rate leads to a decrease in speed (Fig. 6). This shows that the flow rate is determined depending on the operating nominal speed of the motor coupled to the mill. The application of the control strategy has ensured a smooth startup of the mill. This type of start have significantly reduced the current during the transitional phase (Fig. 7). However with the implementation of the control, it's noted a slight delay on starting, linked to the progressive application in voltage on the stator phases. There is also the oscillations of the electromagnetic torque due to modulation as shown in Fig. 8.

4 Conclusion

In this paper, the modeling and simulation of a device with a craft mill controlled by the strategy V/f-SVM are done. The results of simulation, with the characteristics of the craft mill, are satisfactory especially with the possibility to reducing the inrush current at start-up efficiently in the transition phase and to determine the grain flow according to the motor used

References

[1] K. S. Jain and al., «Modeling and simulation of an induction motor,» International Journal of Engineering Research and Development, vol. 10 (4), pp. 57-61, 2014.

[2] C. U. Ogbuka and M. Eng , «Dynamic modeling and simulation of a 3-HP asynchronous motor driving a mechanical load,» The Pacific Journal of Science and Technology, vol. 10(1), 2009, pp. 77-82, 2009.

[3] H. Mbengue, «Le matériel de traitement post-récolte des céréales au Sénégal,» Revue Sénégalaise des Recherches Agricoles et Halieutiques, vol. 2, pp. 68-75, 1989.

[4] P. M. Palpankar and al., «A generalized dynamic model of induction motor using Simulink,» ITSI Transactions on Electrical and Electronics Engineering, Vol. 1(5), pp. 118-122, 2013.

[5] M. Diop and al, «Caractérisation expérimentale et simulation d'un moulin artisanal triphasé,» Afrique SCIENCE, vol. 12(11), pp. 273-281, 2016.

[6] M. Aspalli and al., «Three phase induction motor drive using IGBTs and constant V/F method,» International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 1(15), pp. 463-469, 2012.

[7] A. Idir and M. Kidouche, «Real-time simulation of V/F scalar controlled induction motor using RT-LAB platform for educational purpose,» Proceedings of the International Conference on Systems Control and Informatics, 2013.

[8] H. Ding and al., «A novel dynamic voltage restorer and its unbalanced control strategy based on space vector PWM,» Electrical Power and Energy System Vol.24, pp. 693-699, 2002.

APPENDIX

The parameters of simulation

		R_s	0.85 Ω
f_n	50 Hz	L_r	0.023 H
T_s	$10e^{-3}s$	L_{sr}	0.058 H
V_n	230 V	R_r	1.64 Ω
V_o	10 V	L_r	0.016 H
f_o	2,5 Hz	p	1
V_{dc}	565 V	J	0.05 $kg.m^{-2}$