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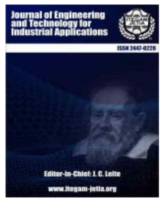

RESEARCH ARTICLE OPEN ACCESS

PROCESS IMAGES-BASED CONTROLLER FUZZY-PI TO CONTROL EFFICIENCY IN ELECTRIC DRIVES

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ABSTRACT

This paper deal about a fuzzy PI tuning from process image-based control system (IBC) for electric drives of hydro-mixture transport, which method use a [r g b] matrix as control vector from process images taken through a inferential sensor of density, to evaluation efficiency in electric drives for hydro-transport of laterite pulp with centrifugal pumps.

I. INTRODUCTION

Image-based control systems (IBC) allows applications used in different fields of social life and industries, due to their safe implementation and constant improvements in the quality of results and applications.

The problem is to evaluate the efficiency of the laterite pulp pumping drive, whose objective is to offer the application of fuzzy logic in energy control in an industrial system.

This set also Electric drives require the rational use of energy, and some processes occur in very adverse environmental environments, where direct measurement of the variables is not possible. Due to this, it is necessary to look for indirect ways or methods of measurement, an aspect that is resolved with the use and advancement of new technologies, using the laws of optical physics, the properties of materials, and the use of Artificial Intelligence (AI) [1].

These aspects allows to use the intelligent qualities of controllers and sensors while maintaining the favorable features offered by devices and accessories in control and measurement schemes in the industrial area. In this way, the information delivered to the sensors is encode in protocols that provide industry 4.0 standard transmission speeds.

Sensors have evolved into non-invasive measurement systems in those complicated means and processes of directly measuring variables, with adequate connectivity properties [1].

The information processed to produce control actions from more flexible schemes to adapt to the natural conditions of industrial processes, using electronic components that promote the design of circuits under the principle of electromagnetism and optical physics.

This work shows an efficiency control procedure in induction motor drive based on tuning a fuzzy PI controller using images taken from the process. The control vector from the pixel arrangements of the matrix [r g b] of the color of the fluid transported by a centrifugal pump, whose mixture characterized by having variable density, which determines the mechanical output power of the electric drive.

The hydro-transport of laterite pulp, involving centrifugal pump drives, constitutes an important link in the nickel production industry, due to its impact on the primary stage of the technological process, which decides the quality of the final product and its appreciable consumption of the energy.

That is why all research focused on improving the energy efficiency of electric drives, with the use of new technologies, constitutes valuable solutions to reduce costs and improve working conditions, which include control schemes and measurements in plants.

The design of a control scheme, in figure 3, with several blocks that includes PI-fuzzy type controllers, a neural controller that operates an inferential sensor (measures density of laterite pulp), which delivers the reference signal to the control. The objective function will be to evaluate the efficiency of the drive based on the density of the transported hydro mixture.

The novelty consists of using the information provided by images taken of the hydro-mixture, its digital processing used by the inferential sensor that offers real-time density values of the laterite pulp and serves as a reference to the input block of the electric drive control system. In this way, a supervisory block addresses the behavior of the induction motor that drives a centrifugal pump, whose rotational mechanical power supplies the load torque requirements of the drive, which depends largely on the value of the density of the hydro mixture at transport. The electric drive model is set out below.

II. METHODOLOGY

II.1 IMAGE-BASED CONTROL

The information provided by the digitally processed pulp images from the inferential sensor blocks (neural networks). A function represented by the color matrices [r g b], and the weights of the mixture [w_1 w_2 w_3] is obtained as control vector at the output of a learning block. The reference signal fuzzy-PI controller operates by error change, responsible for controlling the efficiency of the electric drive, regulating the transport speed of the mixture. This at the same time prevents sedimentation of the material in the pipes.

This type of research is semi-empirical, using the fuzzy logic by inference method, and comparison techniques in the results with conventional logic, using the statistical benefits of processing in MATLAB with the use of the Lookup-Table [2],[3].

An Image-based control system (IBC) offers some advantages of information capture and processing without invading the measurement medium, guaranteeing connectivity, precision and security in communications.

In our case, the control scheme takes into account the specificities of the industrial process, where the hydro-mixture transported at high temperatures, constituting an abrasive medium for the direct measurement of variables, and it is necessary to obtain this information indirectly [1].

The design of an inferential density sensor using a neural network, Figure 2, responsible for processing images of the hydro-mixture and encoding the pixels and piezoelectric measurement of the weight of the mixed fluid into density values in real time [2].

The modern industry has various platforms, such as NVIDIA Drive, which offers powerful computing, with a safe guarantee of being interchangeable.

In our case, the algorithm for extracting image qualities designed to help find a recognition function based on the vectors of the matrix [r g b] and the weight of the object under study, developed during the collection process [4],[5].

The image procedure carried out using fuzzy logic follows the structure, Figure 2, where extracts properties from process images [6]. This follows the similarity of two images, an aspect proposed by [7] and used by [6].

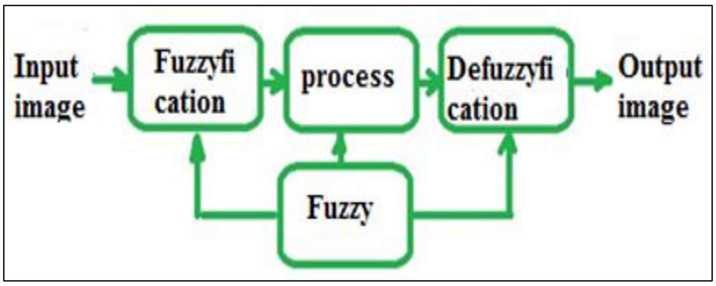

Figure 1: Image processing structure.
Source: Authors, (2024).

In practice, the weight of the variables has priority for the discrimination of fuzzy membership functions. The patterns trained for a high number of classifier samples.

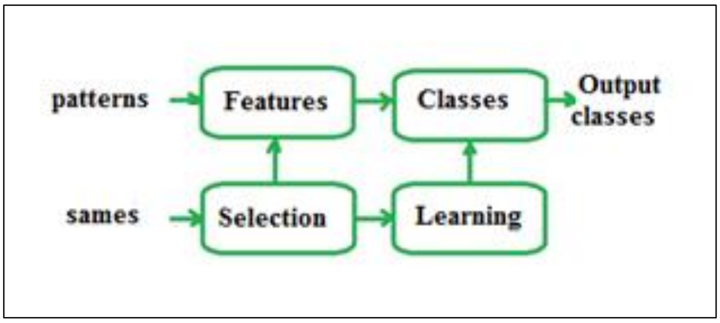

Figure 2: Scheme for patterns classification
Source:[6].

The procedure evaluates color c, weight w of the fluid mixed with suspensions for a monitored medium at a certain temperature τ, as shows the expressions (1), (2) and (3):

$$c = [c_1 c_2 c_3 \dots c_n] \quad (1)$$

$$w = [w_1 w_2 w_3 \dots w_n] \quad (2)$$

$$\tau = [\tau_1 \tau_2 \tau_3 \dots \tau_n] \quad (3)$$

In this way, the control diagram operates taking the reference signal from the image-processing block, as shown in the Figure 3:

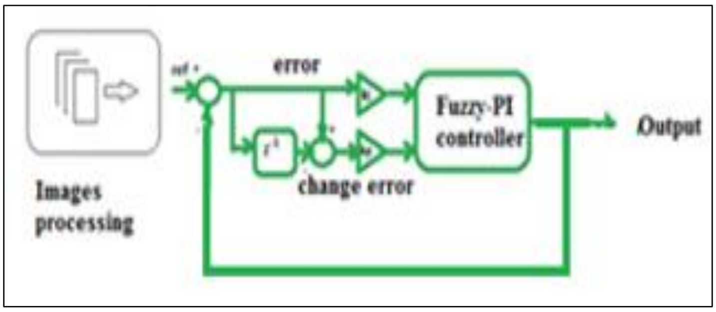

Figure 3: Diagram of fuzzy-PI controller.
Source: Authors, (2024).

The sensors processing information obtained from images, and produce system control actions [3]. It is favorable to implement these types of control schemes that add simplicity and memory converted into intelligence and precision once validated.

This sensor explained in [1], according to Figure 4, consists of two neural blocks in CNN-type cascades, the ANN-1 neural block.

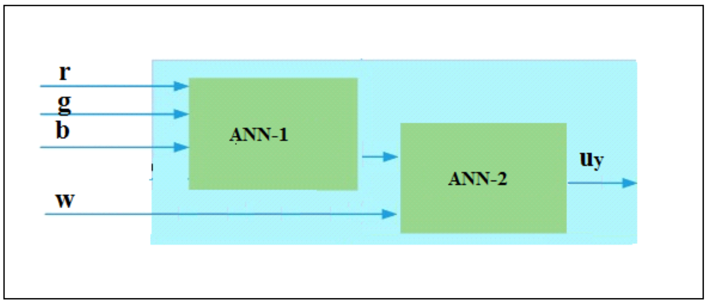

Figure 4: Density sensor based on CNN-type neural networks.
Source: Authors, (2024).

The images processes of the transported fluid and delivers them from each matrix (color, weight) [r g b], [w_1 w_2 w_3] of the flow to the ANN-2 block. The output u_y encodes the density values evaluated by learning procedure to feed reference of the fuzzy-PI controller of the IGBT inverter to PWM.

A learning algorithm that takes into account the color processes the output signal u_y of the neural block. The matrix of the transported flow, developing the speed reference U_r of the fuzzy controller, adjusting more precisely the efficiency control of the pumping drive according to the density values obtained, procedure shown in Figure 5 and Figure 6 [8].

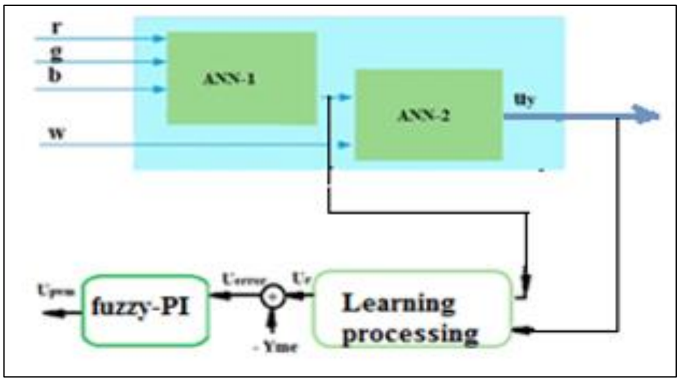

Figure 5: Scheme of control system using fuzzy-PI.
Source: Authors, (2024).

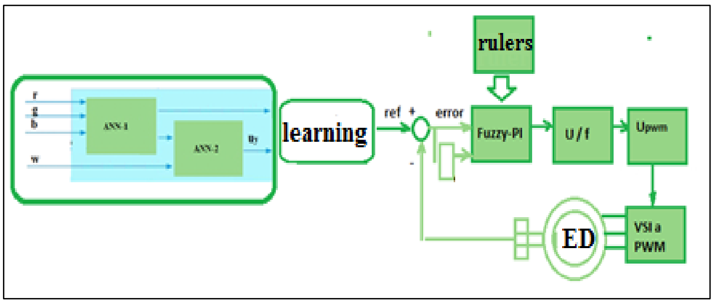

Figure 6: Image-based control diagram of the electric drive.
Source: Authors, (2024).

III. MATERIALS AND METHODS

The experimental part used mixed fluids with temperatures 28, 60 y 90ºC for supervised medium, from 25, 30, 40, 45 y 50 % concentrations of solids, obtained during process industrial metallurgical [1].

In practice, the weighting parameters for the discriminant functions not known a priori. A set of labeled training patterns are used for estimation of the weighting parameters and the efficiency of the classifier is enhanced as a infinite large number of training samples from each pattern class are made available to the classifier [9]. A set of pattern samples are linearly separable, if there exists a weight vector that classifies all the samples correctly.

The Table 1 shows mixed fluid provides as follow.

TABLE 1: MIXED FLUIDS PROPERTIES

Num.	Massa of the mixed fluids		
	Mineral massa kg	Concentration %	Volume %
1	949.3	25	8.78
2	1220.5	30	11.45
3	1898.6	40	19.09
4	2563.2	45	24.8
5	2848	50	28.6

Source: Authors, (2024).

The recognition of the samples by image processing offered the results given in Table II.

TABLE 2: IMAGES RECOGNITION OF MIXED FLUIDS

Color			Matrix and Saturation		Temperature	Density
R	*G*	*B*	matrix	saturation	*ºC*	*Kg/m³*
117	35	11	9	198	90	1046
107	53	20	15	163	90	1105
104	48	23	12	150	90	1190
99	50	29	12	133	90	1230
97	51	31	12	124	90	1235
94	52	34	12	111	60	1275
90	54	37	13	100	60	1300
88	55	39	13	91	60	1400
84	55	44	12	75	60	1425
82	57	46	13	66	60	1488
78	58	50	13	52	28	1500
75	60	52	13	42	28	1568
73	60	54	12	35	28	1650
71	61	58	10	26	28	1663
69	61	58	8	19	28	1750

Source: Authors, (2024).

The inferential sensor of density works through a fuzzy inference system FIS, with inputs: images matrix [r g b], and weight (w) of samples, and output: density (d) of the mixed fluid. All the samples taken equal temperature conditions.

III.1 MODEL OF ELECTRIC DRIVES

The induction motor drive that drives a centrifugal pump has a well-known vector control model whose components in its dd-qq axes presented below [10],[11].

The relationships between the currents and voltages in the dd-qq axes with their components defined by the following expressions (4), (5), (6):

$$\sigma L_s \frac{di_{ds}}{dt} = -R_s i_{ds} + \omega_e \sigma L_s i_{qs} + U_{ds} \tag{4}$$

$$\sigma L_s \frac{di_{qs}}{dt} = -R_s i_{qs} - \omega_e \sigma L_s i_{ds} - \omega_e \frac{L_m}{L_r} \psi_{dr} + U_{qs} \tag{5}$$

$$\psi_{dr} = i_{ds} L_m \tag{6}$$

The torque electromagnetic M_{em} taken by (7):

$$M_{em} = 1{,}5 p(\psi_{sd} i_{sq} - \psi_{sq} i_{sd}) \tag{7}$$

where,

p – is number of poles of the electric motor.

ω_e – is the angular frequency of the motor stator field, [rad/s].
U_{ds}, U_{qs} – are stator voltages in the motor on the dd-qq axes, [V].
U_{dr}, U_{qr} – are rotor voltages in the motor on the dd-qq axes, [V].

i_{ds}, i_{qs} – are stator currents in the motor on the dd-qq axes, [A].

i_{ds}, i_{qs} – currents rotor in the motor on the dd-qq axes, [A].

ψ_{ds}, ψ_{qs} – magnetic fluxes in the stator on the dd-qq axes, [Wb].

ψ_{ds}, ψ_{qs} – magnetic fluxes in the rotor on the dd-qq axes, [Wb].

L_s, L_r – inductances stator and rotor in the winding of motor, [mH].

L_M – mutual inductance in the electric motor, [mH].

σ - Blonde coefficient.

The efficiency of the induction motor defined by follow equation (8):

$$\eta_{MI} = \frac{P_s}{P_e} = \frac{P_s}{P_s + \Delta p} = \frac{P_e - \Delta p}{P_e} \quad (8)$$

where,

Ps – is the output power on the induction motor shaft, [kW].
Pe – is the input electrical power of the induction motor, [kW].
Δp – are the total losses in the induction motor, [kW].

The input power of the drive obtained from (9) as:

$$* \ P_e = I_{ds}.U_{ds} + I_{qs}.U_{qs} \quad (9)$$

The total component of the stator current in the quadrature axes has as module by equation (10):

$$I_s = \sqrt{(I_{ds})^2 + (I_{qs})^2} \quad (10)$$

In such a way that I_{ds}* and I_{qs}* serve as commands during loss control. With changes in I_{ds}, the rotor flux Ψ_{dr} is controlled and with it the torque of the induction motor, which changes the input power.

III.2 ALGORITHM FOR EFFICIENCY CONTROL

A fuzzy inference system (FIS) shown for PID control using a MATLAB and another for image-based control using neural blocks.

This fuzzy inference system (FIS) takes input and output data from the measurement system in the drive, such as a typical controller with two inputs (error and change of error) and one output signal U_y. See Figure 5.

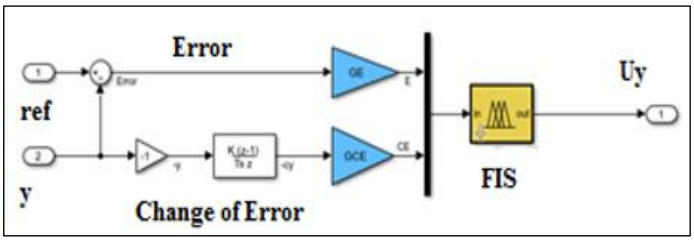

Figure 5: Linear control with input signals Error and Change of Error and output u_y.
Source:[2].

For control applications, it is typical to have as inputs the absolute value of the error (|e(k)|) and the change of error (|e(k)-e(k-1)|), which would be Error |E| and Change of Error |CE| respectively on the surface curve. The fuzzy outputs is the control action $|u_y|$ inferred from the fuzzy rules [2].

A Sugeno-type Fuzzy Inference System FIS operates linear control from the input signals: Error |E| and change of Error change |CE| at the exit $|u_y|$. The adjustment procedure explained following publication [2]. Input signals with triangle-type membership functions with neighboring values, whose output signal is set as a constant. The algorithm follows a relationship given in the surface curve of Figure 6 [12].

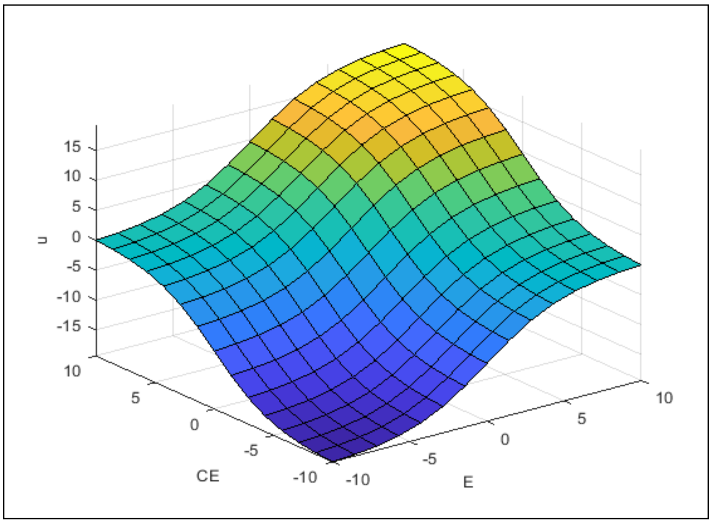

Figure 6: Surface curve for fuzzy-PI control.
Source: Authors, (2024).

IV. RESULTS AND DISCUSSIONS

In order to demonstrate the quality of the fuzzy control using images of the process, the graphs of the stable behavior of the variables voltage and control commands of the induction motor presented, using this type of control.

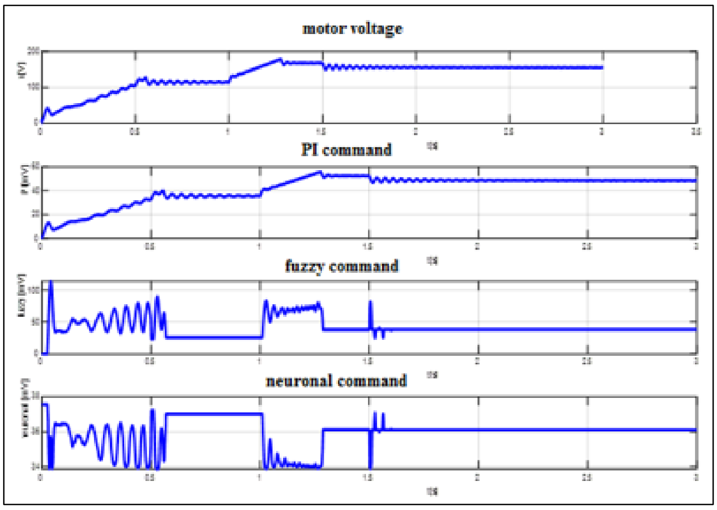

Figure 7: Motor voltage signals and control commands with PI, fuzzy and neuronal sensor.
Source: Authors, (2024).

For changes in the density of the lateritic pulp, cause changes in the mechanical load and is the magnetic flux of the machine adjusted. This behavior observed in Figures 8 and 9.

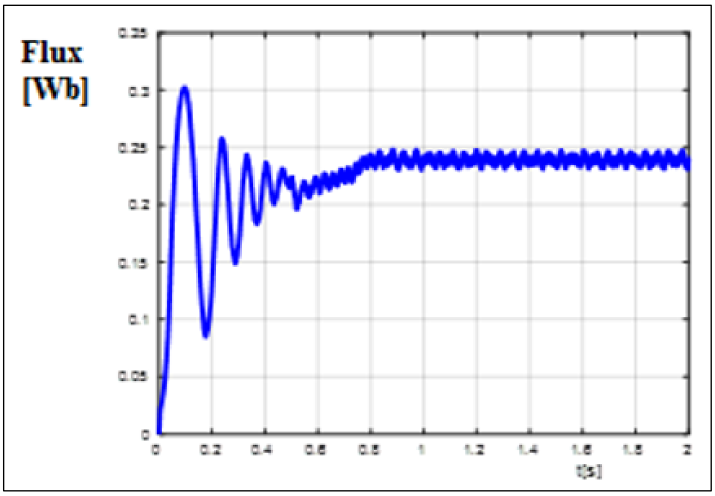

Figure 8: Magnetic flux of the motor with Fuzzy-PI controller for 950 rpm.
Source: Authors, (2024).

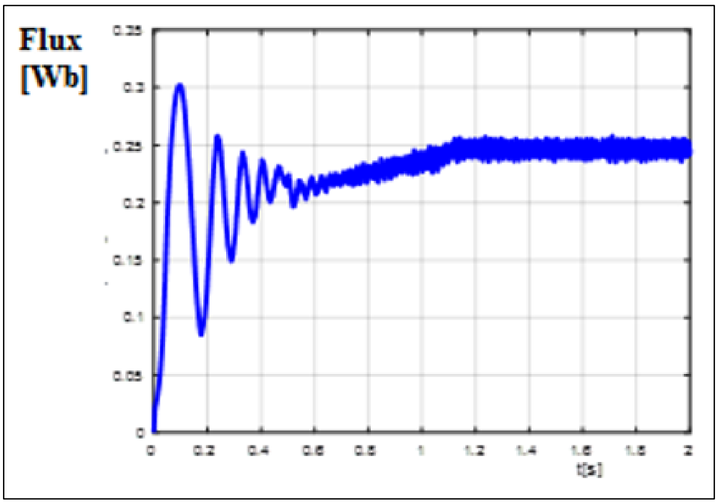

Figure 9: Magnetic flux of the motor with Fuzzy-PI controller for 1500 rpm.
Source: Authors, (2024).

Comparing conventional PI control and the use of fuzzy-PI control, steel losses decreased, and aspect observed in figure 10, where efficiency is better.

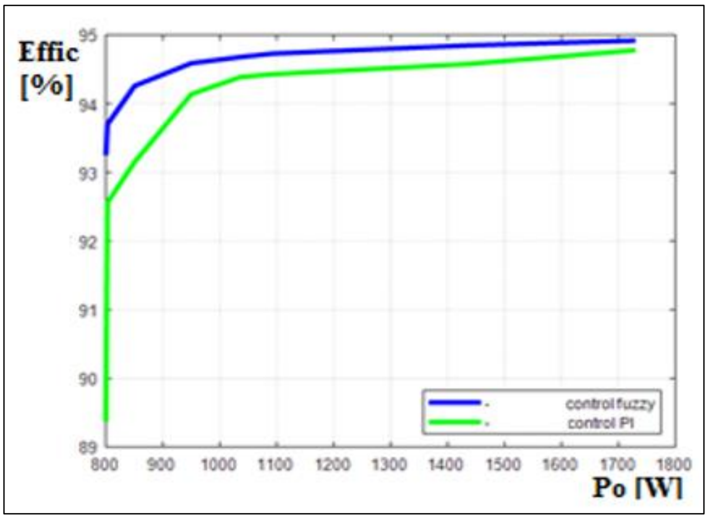

Figure 10: Efficiency by fuzzy-PI control with respect to conventional PI.
Source: Authors, (2024).

Observing the effect of the frequency change with respect to motor losses, Figure 11, the improvement with fuzzy-PI control better.

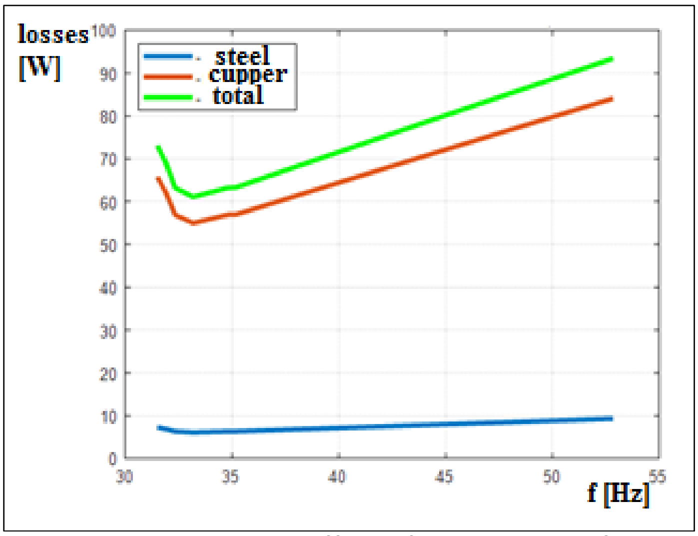

Figure 11: Motor losses at different frequencies with fuzzy-PI control.
Source: Authors, (2024).

These graphs show the novelty of how to tune the fuzzy-PI controller using the encoding of the images obtained from the transported fluid.

Thus is possible to control the efficiency of the centrifugal pump drive, through a control function obtained according to the density values of the transported pulp that determines the mechanical load of the electric drive for the most efficient speeds of lateritic pulp pumping.

The novelty consists of controlling the efficiency of the centrifugal pump drive, using image processing of the pulp transported in the hydro-transport process.

V. CONCLUSIONS

The use of image-based control in electric drives with induction motors for centrifugal pumps used for hydro-transport of mixed fluids in industrial environments conditions can be to overcome the limitations of direct measurements and allow monitoring efficiency in these drives.

For future work, is possible to improve the research using less saturated mixture fluids to evaluate the efficiency of an electric drive from on images of the process in order to implement intelligent control.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Luis D. Rojas, Idania Aguilera and Luis Rojas Aguilera.
Methodology: Luis D. Rojas and Idania Aguilera.
Investigation: Luis D. Rojas, Idania Aguilera and Luis Rojas Aguilera.
Discussion of results: Luis D. Rojas Purón and Luis Rojas Aguilera.
Writing – Original Draft: Luis D. Rojas.
Writing – Review and Editing: Luis Rojas Aguilera.
Resources: Luis Rojas Aguilera.
Supervision: Luis D. Rojas Puron.
Approval of the final text: A Luis D. Rojas, Idania Aguilera and Luis Rojas Aguilera.

VII. ACKNOWLEDGMENTS

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