HBRP PUBLICATION

Recent Trends in Analog Design and Digital Devices
Volume 6 Issue 1

Analysis of Speed Control of Three Phase Induction Motors with Constant Voltage Frequency Ratio

Thank God Ichem, Emmanuel Chinweikpe Obuah*, Wonodi Ikonwa, Christopher Okechukwu Ahiakwo
Department of Electrical Engineering, Faculty of Engineering, Rivers State University, Port Harcourt, Nigeria

Corresponding Author
E-Mail Id: emmanuel.obuah@ust.edu.ng

ABSTRACT
Due to their dependability, low cost, and robustness, induction motors are the most widely used electrical motors. However, induction motors is a constant speed machine; hence it speed control is difficult. Electric drive system is increasingly required to meet the higher performance and reliability requirement of motors used in industrial applications. This work presents speed control of a three-phase induction motor with constant voltage frequency (v/f) ratio scheme with peripherial intergral (PI) controller. In this method of constant v/f ratio, by use of rectifier and pulse width modulation (PWM) inverter, the supply voltage as well as the supply frequency is varied such that the voltage and frequency ratio of the motor remains constant and the flux remains constant too. Dynamic equations of the motor were written as well as the steady state equation based on Parks two-axis theorem. The equations were validated in MATLAB. With reference speed of 1500 rpm at diiferent load, results shows that the maximum torque of the motor remains unchanged at different operating zone for various speeds and given load, the maximul torque being 2.2 Nm at steady state opration. The work was done using a three-phase, 4-pole 50Hz, 155 volts, 1.8 kW induction motor.

Keywords: *Three-phase induction motor, speed control, electromagnetic torque, constance v/f, PI*

INTRODUCTION

Induction motors are the most generally utilized in homegrown, business and different modern applications. Especially, the squirrel rotor type is described by its toughness and minimal expense, which has consistently made it exceptionally alluring, and it has in this manner caught the main spot in modern areas.

Because of its broad use in the business, induction motors consume an impressive level of the general delivered electrical energy [1]. The minimization of electrical energy utilization through a superior engine configuration turns into a main issue. Numerous useful streamlining issues in advancement of the electromagnetic systems have blended (consistent and discrete) factors and discontinuities in search space [2]. On the off chance that the standard non-straight programming (NLP) procedures were to be utilized in such cases, then they would be computationally extravagant and wasteful. A few applications using the standard NLP strategies incorporate the plan enhancement of induction motors.

The utilization of three-phase induction motors will keep on expanding because the machines are rocky in development, which gives them an intrinsically high dependability and strength. For this reason, they are generally called the workhouse of industries. Once more, the three-phase induction motors do not need external power source for excitation. Again, they do not utilize capacitos for stating; and they are accessible in power range from a negligible part of a kW to a few MWs contrasted with their three-stage partners. They endlessly are appropriate for by far most of drive applications including consistent speed, for example siphons, fans, blowers, transports, moving plants.

Present day patterns and improvement of speed control techniques for three-phase motors have likewise cultivate the expanded in the interest of acceptance machines in electrical drives broadly. [3,4].

One of the issues of the three-phase induction motors is that its speed is challenging to control. It is realized that the motors comprise of posts conveying supply current to incite an attractive field that infiltrates the rotor, when provided with power. The recurrence of the current and voltage in the rotor circuit is subject to the overall speed between the field magneto motive force (mmf) and the speed of the rotor (slip speed). This frequency is known as the frequency of the rotor current. So, under light load, the motor power factor is lagging; and under heavy load, the motor runs sluggishly.

In the first time, different speed control measures have been proposed. These include the pole pair changing method, variable stator voltage method variable stator and rotor resistance method, both the constant voltage frequency ratio approach and the adjustable speed method.

The drawback of this speed control approach for pole pair change, is that it is used in low performance drives that typically require operation at two distinctly different operating speed (say, a washing machine); and spinning is done at high speed, while normal washing cycle takes place at low speed) [5]. Again, the universality of this approach is limited to situations where two distinct speed values, rather than constant speed variation, are required. Control the speed by pole pair changing necessitates a specially injured stator and is typically discovered by mechanically reuniting the stator from one pole couple number to the other [5].

This method is the simplest and least expensive for changing the stator voltage. This application is only suitable in drives that run for prolonged periods of time with very light loads. This is also replica for the variable frequency method because when frequency is varied, the rms value of the supply voltage also varies [4]. For variable stator and rotor resistance, it is revealed that increase in stator or rotor resistance can cause the motor to develop more jerks on startup, change the shape of the run-up speed and torque [6].

For constant voltage frequency ratio, a wide speed control range with an induction machine can be realized only as the stator frequency is made constant with the supply voltage keeping the flux constant. It has been realized that the constant voltage frequency ratio is the most efficient method, however, this method is ineffective when it comes to accuracy and precession [5].

[7] utilized an artificial neural network (ANN) regulator is union and preparing disconnected to decide the ideal motion level that accomplishes most extreme drive effectiveness. [8] utilized a brain organization to look through in the vector control of induction motor drive framework. In light of the consistent state induction motor model, the machine power misfortunes are determined as a preparation information. The back proliferation learning calculation is utilized to prepare the brain network regulator in various working point. Their proposed brain control model has one info layer, two

secret layer and one result layer. The info layer comprises of speed and burden force reference signals. The result layer has just a single neuron for the charging current. The main secret layer has ten neurons and the second secret layer has five neurons. Since power electronic frameworks and drives have complex non-direct construction with boundary vulnerability, fluffy rationale is very reasonable for power devices and motion control in ideal looking, [9] have used fluffy rationale.

[10] inspected the Fuzzy rationale based speed control of roundabout field situated controlled three-phase star connected induction motor.

The paper presented a speed control of two three-phase star induction motor working in equal design with backhanded field-situated control utilizing a Fuzzy rationale regulator is the show that the three-phase motor are associated in lined up at the result of a solitary six stage PMW based inverter took care of from a DC source. Reproduction was utilized to concentrated on the exhibition of the proposed technique under load unsettling influences. The speed reaction with two control is thought about and its outcomes is introduced and dissected.

[11] proposed one stage change of voltage, independent of burden change. Be that as it may, they have proposed keeping away from too enormous decrease in voltage since it will bring about bigger slip which will prompt unfortunate productivity, high rotor warming and in any event, pulling out and motoring slowing down. [12] have proposed the hunt regulator in the scalar control model by adaptively getting the stator voltage per hertz proportion utilize Fuzzy logic regulator. Contribution of the Fuzzy rationale regulator is the difference in input power and volt per hertz proportion. The result is the new difference in volt per hertz proportion. Another creator proposed the hunt regulator in the scalar control model by adaptively lessening the stator voltage reference with the utilization of a Fuzzy regulator. The force throb issue is overwhelmed with the assistance of feed-forward throbbing force pay. Contribution of the fluffy rationale regulator is stator voltage and info power and the result is the voltage reference compensator [13].

The analysis of three-phase induction motors required a sound knowledge of their behavior and principal characteristics. From the electrical machine point of view, it is necessary to consider the relationship between the electromagnetic torque and speed, obtained an equivalent circuit of the machine representing the operations.

It is clear that most of the techniques for power electronics and motion control of electric machines mentioned from existing literature such as the ANN and Fuzzy logic are giving a satisfactory result for machine optimization and control. However, they are complex and sophisticated [14]. Hence, a simpler approach which is the use of voltage frequency ratio PMW drive and PI is presented. It is believed that this will still achieve a desirable result in an easier way.

METHOD

The work shall include simulation or validation of three-phase induction motor based on Park's d-q techniques. Simulation and validation are conducted using MATLAB software for controller design and implemented of the PI, and for testing of the controller to verify the correctness of the models. In this paper the following simplifying assumptions have been made: Core losses, Eddy current and hysteresis effects are negligible.

Recent Trends in Analog Design and Digital Devices
Volume 6 Issue 1
DOI: [To be assigned]

$$p\lambda_{qs} = V_{qs} + \omega_r \lambda_{ds} + i_{qs} r_s \quad (1)$$

$$p\lambda_{ds} = V_{ds} + \omega_r \lambda_{qs} - i_{ds} r_s \quad (2)$$

$$p\lambda_{qr} = V_{qr} + (\omega_s - \omega_r)\lambda_{qr} + i_{qr} r_r \quad (3)$$

$$p\lambda_{dr} = V_{dr} + (\omega_s - \omega_r)\lambda_{dr} + i_{dr} r_r \quad (4)$$ where

$$\lambda_{qr} = (L_{ls} + L_m) i_{qs} + L_m i'_{qr} \quad (4)$$

$$\lambda_{dr} = (L_{ls} + L_m) i_{ds} + L_m i'_{dr} \quad (5)$$

$$\lambda'_{qr} = (L'_{lr} + L_m) i'_{qr} + L_m i_{qs} \quad (6)$$

$$\lambda'_{dr} = (L'_{lr} + L_m) i'_{dr} + L_m i_{ds} \quad (7)$$

r_s is the stator resistance, r_r is the rotor winding resistance i_{qs} is the stator current in the q-axis, i_{ds} is the stator current in the d-axis, L_{qs} is the stator inductance in the q-axis, L_{ds} is the rotor inductance in the d-axis, i'_{qr} is the rotor current in the q-axis, i'_{dr} is the stator current in the d-axis, L'_{qr} is the rotor inductance in the q-axis, L'_{dr} L'_{dr} is the rotor inductance in the d-axis L_m , L_m is the stator-rotor mutual inductace, L_{ls}, and L'_{lr} are the stator and the rotor leakage inductance respectively, p is the operator of the derivatives d/dt , ω_s is the synchronous speed in rad/sec and ω_r is the rotor speed in rad/sec.

For a squreel cage induction motors, where the rotor conductors are short-circuited, the overall voltage equation is expressed as (8).

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} r_s & 0 & 0 & 0 \\ 0 & r_s & 0 & 0 \\ 0 & 0 & r_r & 0 \\ 0 & 0 & 0 & r_r \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} + p \begin{bmatrix} \lambda_{qs} \\ \lambda_{ds} \\ \lambda_{qr} \\ \lambda_r \end{bmatrix} + \begin{bmatrix} \lambda_{qs} \\ \lambda_{ds} \\ \lambda_{qr} \\ \lambda_{dr} \end{bmatrix} \begin{bmatrix} 0 & \omega_r & 0 & 0 \\ -\omega_r & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

(8)

The d-q equivalent circuit of the motor is illustrated in Figure 1 when there are rotor conductors.

Recent Trends in Analog Design and Digital Devices
Volume 6 Issue 1
DOI: [To be assigned]

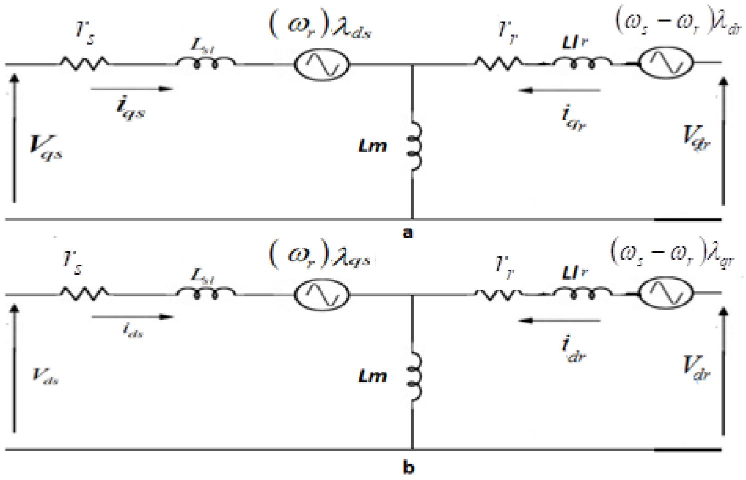

Fig. 1: *d-q representation of equivalent circuit of induction motor with rotor conductors.*

The steady-state eqauations can directly be obtained from the dynamic equations when the derivative terms in the dynamic voltage equation are made zero [15] and [16]. So, from equation (1) through (3), the steady-state stator voltage equation, maximum slip and torque of the machine are expressed as (9), (10) and (11) respectively.

$$V_{as} = r_s i_{as} + jX_{ls} i_{as} + jx_m (i_{as} + i'_{ar}) \quad (9)$$

$$s_{\max} = \pm \frac{r_r}{\sqrt{(r_s)^2 + j(X_s + X'_r)^2}} \quad (10)$$

$$T_{\max} = 2\omega_s \frac{V^2_{as}}{\sqrt{(r_s)^2 + j(X_s + X'_r)^2} \pm r_s} \quad (11)$$

i_{as} and i'_{ar} are the steady state stator current, X_s and X'_r are the steady state stator and rotor reactancet, and X_m and X_{ls} are the steady state mutual and leackage reactance.

RESULTS AND DISCUSSION

To demonstrate the characteristic of the three-phase motors, the equations that describes the henaviour of the machine were developed in MATLAB. The results for the dynamic characteristris of the motor is found in Figure 2 through Figure 6 at no-load torque, while Figure 7 shows the stseady-state characteristic with variable loads. In Figure 2, the initial current obtained during start up is high, abouts 94 A at 0 to 0.5 seconds, before the current became stable. This is a feature of induction motor, which is high starting current. The stator phase voltages are shown in Figure 3. The balanced the three-phase voltages shows that each phase of the motor is 120 degrees (electrical) displaced from each other, maintaining a balance voltage of 155 V. In Figure 4, the electromagnetic torque is shown. The oscillation started from 0 seconds up to about 7 seconds given different values of torque from the starting torque of about 450 Nm, before stability was attained at 0 Nm. The rotor speed is illustrated in Figure 5. The speed build-up started with a jerk from 0 seconds to about 7 seconds, given a norminal speed of 1500 rpm.

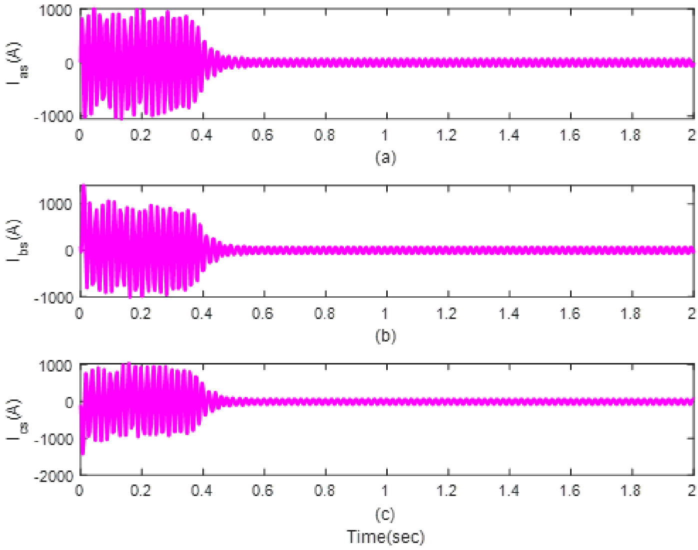

Fig. 2: *Dynamic response of the motor stator phase currents, (a) phase A current, (b) phase B current, (c) phase C current.*

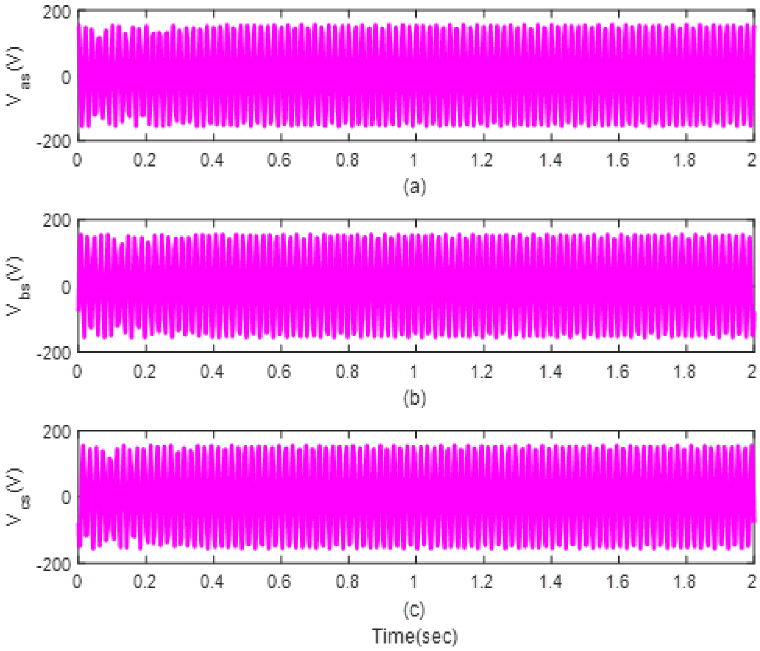

Fig. 3: *Dynamic response of the motor stator phase voltages, (a) phase A voltage, (b) phase B voltage, (c) phase C voltage.*

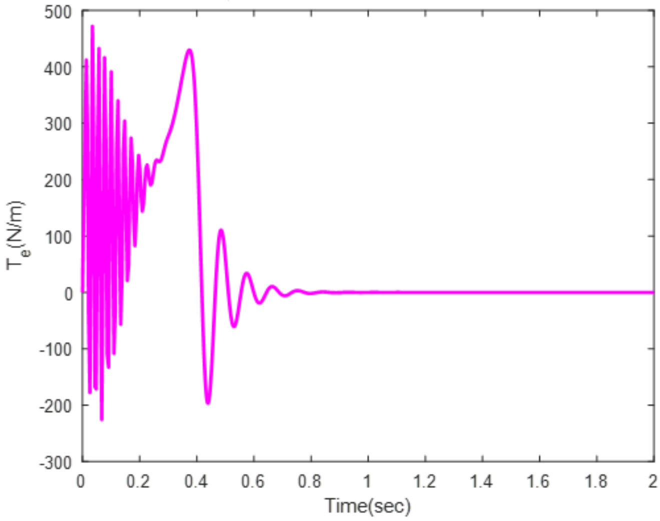

***Fig. 4:** Dynamic response of the motor electromagnetic torque.*

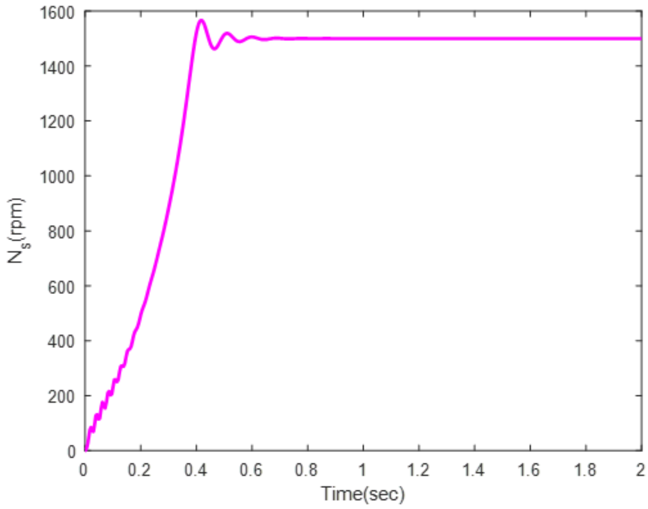

Fig. 5: *Dynamic response of the motor speed.*

It is well known that the three-phase induction motor is a constant speed machine. To investigate the dynamic characteristics of the induction generator utilizing a closed loop constant v/f control approach with a PI voltage source inverter, a MATLAB model was created as well. By concurrently altering the supply frequency so that the ratio v/f stays constant, the stator voltage is changed while keeping the flux constant. Figure 6 shows the rotor speed with time. The reference speed is in purple colour while the motor speed is in yellow colour. The reference speed is set at 1500 rpm maximum; and the motor was operated at variable loads. The reference speed is used for measuring and comparing the rotor speed at different loads. The proportional controller processes the inaccuracy this causes as a result of the variable loads; and adjusts the supply frequency accordingly. However, it takes around 0.2 seconds for the motor speed to become proportionate to the rated speed.

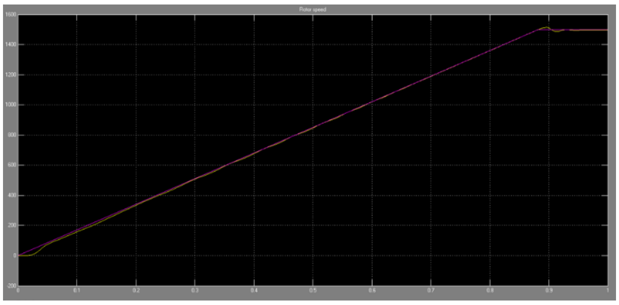

***Fig. 6:** Dynamic response of the motor speed on constant v/f scheme with PI.*

The steady-state plot of the motor speed control using constant v/f with PI is shown in Figure 7 for a refrence speed of 1500 rpm. It has been noted that more initial torque is produced prior to control. Additionally, the starting torque, which is zero is regulated for the reference speed queueing system until it reaches its maximum, which is 2.2 Nm. Applying a variable amplitude and variable frequencies voltage to the motor serves as the foundation for constant v/f speed control of the motor, the motor speed is adjusted using voltage source converters and constant current inverters. The voltage is also adjusted such that the v/f ratio is constant when the control system feeds the voltage source inverter. This maintains a consistent flux value across the speed range, which in turn guarantees a constant max torque. So, speed control is accomplished at different loads.

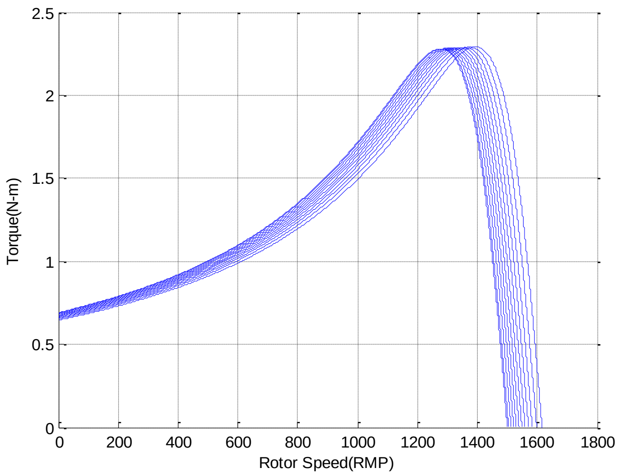

***Fig. 7:** Steady state torque-speed characteristics of the induction motor on constant voltage-frequency ration with PI.*

CONCLUSIONS

This paper has presented analysis of control of a 1.8 kW three-phase induction motor using constant v/f schem with PI controller voltage source inverter. The steady state performance equations and analysis of the motor was obtained using Parks d-q reference frame model; and the models were implemented in MATLAB. With the PI controller, the voltage is adjusted such that the v/f ratio is constant when the control system feeds the voltage source inverter. This maintains a consistent flux value across the speed range, which in turn guarantees a constant max torque. So, speed control is accomplished at different loads.

REFERENCES

1. Malik, N. R. (2012). *Analysis and control aspects of brushless induction machines with Rotating Power*

Electronic Converters (Doctoral dissertation, PhD thesis, Royal Institute of Technology, Stockholm, Sweden).

2. Bechir, R. E. B. H. I., Mabrouka, L. A. A. B. I. D. I., & Mohamed, E. L. L. E. U. C. H. (2013). Boosting the induction motor with the Technique of discrete frequency control. *Journal of Electrical Engineering*, *13*(2), 9-9.
3. Aspalli, M. S., Kumar, V., & Hunagund, P. V. Development and Analysis of Variable Frequency Three Phase Induction Motor Drive. *IJ-ETA-ETS*, *3*(2), 129-195.
4. Samuel, J. D., Braide, S. L., & Idoniboyeobu, D. C. (2020). Performance Evaluation of Three Phase Induction Motor in Arbitrary Reference Frame. *GSJ*, *8*(12).
5. Aspalli, M. S., Asha, R., & Hunagund, P. V. (2012). Three phase induction motor drive using IGBTs and constant V/F method. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, *1*(5), 463-469.
6. Obuah, E. C., Inyenemi, M. (2018). Effect of design parameters on the performance of three-phase induction motor. *International Journal of Electrical Machines and Drives*, *4*(1).
7. Luo, X., Liao, Y., Toliyat, H. A., El-Antably, A., & Lipo, T. A. (1995). Multiple coupled circuit modeling of induction machines. *IEEE Transactions on industry applications*, *31*(2), 311-318.
8. Levi, E., Lamine, A., & Cavagnino, A. (2006). Impact of stray load losses on vector control accuracy in current-fed induction motor drives. *IEEE Transactions on energy conversion*, *21*(2), 442-450.
9. Qu, Z., Ranta, M., Hinkkanen, M., & Luomi, J. (2012). Loss-minimizing flux level control of induction motor drives. *IEEE Transactions on industry applications*, *48*(3), 952-961.
10. Tir, Z., Malik, O. P., & Eltamaly, A. M. (2016). Fuzzy logic based speed control of indirect field oriented controlled Double Star Induction Motors connected in parallel to a single six-phase inverter supply. *Electric Power Systems Research*, *134*, 126-133.
11. Purwahyudi, B. (2017, August). Double fuzzy-pi controller based speed control of permanent magnet synchronous motor. In *Proceedings of The 2017 International Conference on Technology and Applications* (pp. 23-30). Fakultas Teknik Universitas Bhayangkara Surabaya.
12. Kouki, M., Fredj, M.B., Rehaoulia, H. (2017). Research Laboratory SIME. *ENS1T*, University of Tunis, Tunisia, 56-1008.
13. Tan, W. W., & Huo, H. (2005). A generic neurofuzzy model-based approach for detecting faults in induction motors. *IEEE Transactions on Industrial Electronics*, *52*(5), 1420-1427.
14. Marungsri, B., Meeboon, N., & Oonsivilai, A. (2006). Dynamic Model Identification of Induction Motors using Intelligent Search Techniques with taking Core Loss into Account. *WSEAS transactions on power systems*, *1*(8), 1438.
15. Krause, P. C., & Thomas, C. H. (1965). Simulation of symmetrical induction machinery. *IEEE transactions on power apparatus and systems*, *84*(11), 1038-1053.
16. Krause, P. C., Wasynczuk, O., & Sudhoff, S. D. (1969). Analysis of electric machinery and drive systems.