IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 16, Issue 1 Ser. I (Jan. – Feb. 2021), PP 30-37
www.iosrjournals.org

Induction Machine Speed Control: A survey.

Akpama, E. J.[1], Nwiwure, D. E.[2], Agbeb N.S.[3], Badom F.Z.[4]
[1,]Elect/Elect Engineering, Cross River University of Technology, Calabar, Nigeria.
[2,3,4]Elect/Elect Engineering, Ken Saro-Wiwa polytechnic PMB 20 Bori. Rivers State, Nigeria.

Abstract
The asynchronous machine is one of the most widely used electrical machines as industrial drive system. The induction motors have numerous commercial and industrial applications. This paper presents a survey of induction machine control based on current discoveries, comparing the different techniques.The advances in semi-conductor and power electronics has made some machines drives obsolete. The adaptive and intelligent control schemes have in recent years taken over from conventional control methods.The control of induction machine (speed and torque) is very important inmost industrial operations. However, the review of different method of speed and torque control with relativemodelswill be investigated. The sample motor is a three phase, 50Hz, 2.2kW machine, the control design is with reference to speed and torque control loop and current regulation that can overcome the limitation of sluggish response of volts per hertz controlled method. A constant volt/hertz (V/f) mode of operation is chosen for its advantages and popularity in motor speed control. The control design can be of proportional plus integral (PI) controller,and Fuzzy logic controller with regard to vector control. However, the Fuzzy Logic controller (FLC)is used to compare the PI controller in this work. Matlab/Simulink model is designed and simulated for the control. The simulated results show that Fuzzy logic based controller produced a better control performance when compare with PI controller in term of speed and torque control.

Keywords: *Induction motor, speed, torque, PI controller, MRAC Fuzzy logic controller.*

Date of Submission: 08-01-2021 Date of Acceptance: 24-01-2021

I. Introduction

The first AC commutator-free three-phase induction motors were independently invented by Galileo Ferraris and Nikola Tesla, a working motor model having been demonstrated by the former in 1885 and by the latter in 1887.In other words, Nikola Tesla invented the induction machine in 1887. Today, the induction machine has become the workhorse of the industry. Processing industries cannot operate effectively without one or more induction motors for daily operation. This motors can perform multifunction activities and may drive different types of loads, hence,system control and automation becomes imperative,[1].AC motors are categorized as Synchronous and Asynchronous machines. Asynchronous motors are used to drive continuously equipment that require constant speed such as; centrifugal pump, fan, blower, air compressor etc, [2-5]. But, for more than a decade, the induction machine have been used at fixed speeds. Meanwhile, the DC machines have been used for variable speed application using the ward-Leonard arrangement. The Ward-Leonard configuration requires two DC machine and one induction motor, this setup is considered very bulky and expensive.The introduction of power electronics where new impulse was given to variable speed control application of both DC andAC machines,in which the use of thyristor control enable high performance of torque, speed, as well as flux control. However, the variable speed induction motor drives usemostly the pulse width modulation techniques for polyphase generation at specific frequencies.

The most recognised type of three phase machine is the squirrel cage AC induction motor, which is characterise as a noise less, less maintenance cost and efficient motor whose stator is supply by a balance three phase AC power source, [7].The three phase AC induction motor is of two types; squirrel cage and slip ring or wound rotor induction motor or phase wound induction motor, which require external resistor to have high starting torque.However, the squirrel cage motor has a drawback as a result of poor starting torque due to low rotor resistance. The starting torque is directly proportional to the rotor resistance. This drawback can be overcome by the use of double squirrel cage motor. The control of induction motor in recent years has been improved by the rapid use of microprocessor and power electronics, [8].The squirrel cage induction motor has been classify in-terms of starting mode as class A, B, C, D, E, and F, as assert by NEMA (National Electrical Manufacturer's Association) and IEC, [9].

II. Induction Motor Mathematical Modelling Equation

The induction machine are different from other types of electric motor, owning to the fact that the secondary current are produced by induction and not by dc exciter or other source as in other machines. The equivalent circuit of the induction motor is shown below in figure 2.[10] Assert that, the dynamic behaviour of voltage and torque equation of an induction motor is time varying. The induction motor model is similar to that of the transformer, having stator being equivalent to the primary and the rotor to be the secondary. The air gap between the stator and rotor is considered as the core of the transformer. The stator winding perform basically the same function like that of the transformer primary winding.

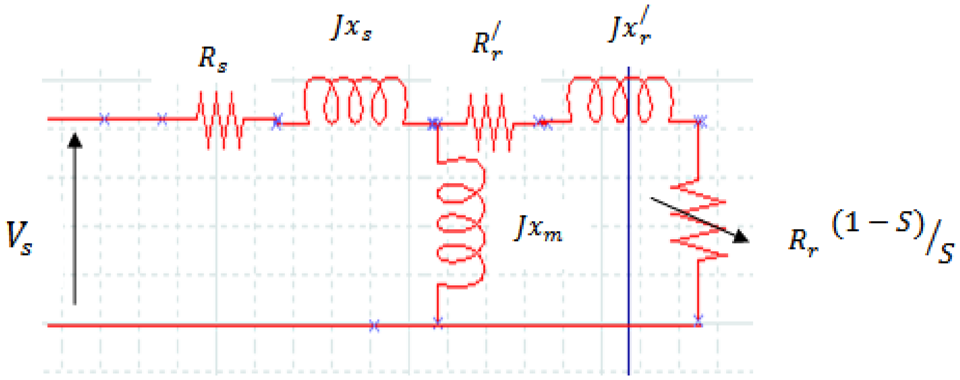

Figure 1: Equivalent circuit of an induction motor

Where; V_s is source voltage, x_s , x_r are stator and rotor reactance, R_s , R_r are stator and rotor resistance. From the equivalent circuit equations (1) is developed

The resistance $R_2^/$ is called the rotor resistance as referred to stator. However, the rotor current, $I_2^/$ can be determine from ohm's law as shown below;

$$I_2^/ = \frac{sE_2^/}{R_2^/ + jsX_2^/} \qquad (1)$$

Dividing the numerator and denominator by s gives,

$$I_2^/ = \frac{E_2^/}{\frac{R_2^/}{s} + jX_2^/} \qquad (2)$$

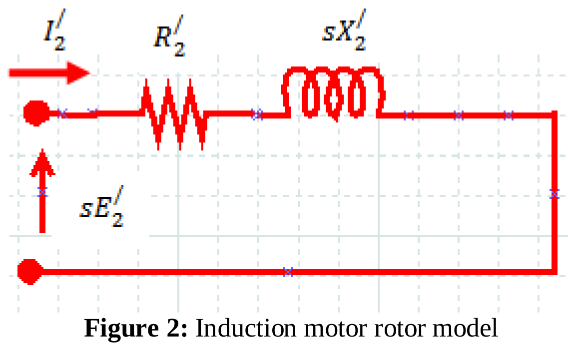

Figure 2: Induction motor rotor model

The circuit for the motor model can then be rearranged as shown in figure 4 below.

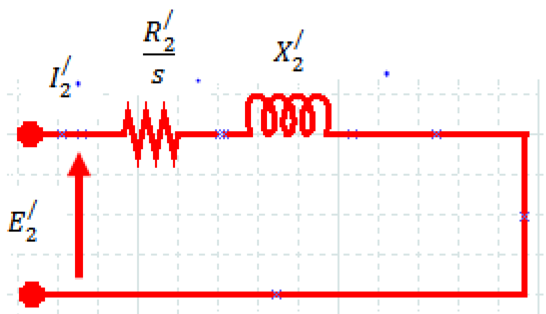

Figure 3: Rearranged motor model

The tree phase induction machine can also be model using the theory of two axis coordinate d and q, as equivalent to induction machine with stator and rotor winding as shown in figure 5 below.

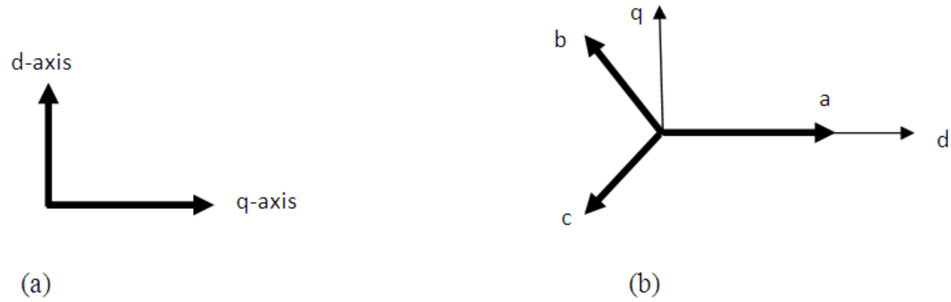

Figure 4: (a) d-q axis of Induction machine, (b) abc sequence Induction machine

The equation below is obtained by applying Kirchhoff's voltage law regarding the induction motor equivalent circuit.

$$\left.\begin{aligned} U_d &= R_1 i_d + \frac{d\Psi_d}{dt} - \omega_1 \Psi_q \\ U_q &= R_1 i_q + \frac{d\Psi_q}{dt} - \omega_1 \Psi_d \end{aligned}\right\} \quad (3)$$

But considering α, β when $\omega_k = 0$ and d-q when $\omega_k = \omega_{sin}$, then equation 3 can also be written as:

$$\left.\begin{aligned} U_s &= R_s i_s + \frac{d\Psi_s}{dt} + j\omega_k \Psi_s \\ U_r &= R_r i_r + \frac{d\Psi_r}{dt} + j(\omega_k - \omega_r)\Psi_r \end{aligned}\right\} \quad (4)$$

Where ω_k is the angular rotation speed of coordinate system and then the squirrel-cage rotor motor equations allowed for derivative flux linkages becomes;

$$\left.\begin{aligned} \frac{d\Psi_{s\alpha}}{dt} &= U_m \cos(\tau) - R_s\, i_{s\alpha}, \\ \frac{d\Psi_{s\alpha}}{dt} &= -U_m \sin(\tau) - R_s i_{s\beta}, \\ \frac{d\Psi_{r\alpha}}{d\tau} &= -R_r\ i_{r\alpha} + \omega_r \Psi_{r\beta}, \\ \frac{d\Psi_{r\beta}}{d\tau} &= -R_r\ i_{r\beta} + \omega_r \Psi_{r\alpha} \end{aligned}\right\} \quad (5)$$

Then $\frac{d\omega_r}{d_\tau} = (M_{em} - M_1) / T_M$ (6)

Where:

$U_m \cos(\tau) - U_m \sin(\tau)$,is the voltage supply to the stator winding,
M_{em}, and M_1 is the torques electromagnetic and of load,
T_M, is the machine time constant measured in electrical radians

III. Induction Motor (Torque, Speed) Control

The torque produced by an induction motor depends on three parameters: (a) the magnitude of the rotor current, (b) the flux which interacts with rotor causing rotation, and (c) the power factor of the rotor.

Mathematically; $T \propto \Phi I_2^{/} \cos\theta_2$ (7)

Where T is the torque produce by the induction motor, Φ is the flux responsible for producing induced electromotive force (emf), while $I_2^{/}$ is the rotor current, and $\cos\theta_2$ is the power factor of the rotor circuit.

But $I_2^{/} = \frac{sE_2^{/}}{R_2^{/} + jsX_2^{/}}$ (8)

Then, $\left|I_2^{/}\right| = \frac{sE_2^{/}}{\sqrt{(R_2^{/})^2 + (sX_2^{/})^2}}$ (9)

And,

$$\cos\theta_2 = \frac{R_2^{/}}{\left|Z_2^{/}\right|} = \frac{R_2^{/}}{\sqrt{(R_2^{/})^2 + (sX_2^{/})^2}} \qquad (10)$$

Therefore,

$T \propto \frac{\Phi s E_2^{/} R_2^{/}}{(R_2^{/})^2 + (sX_2^{/})^2}$ (11)

Since$E_2^{/} \propto \Phi$,as illustrated by transformer equation, then;

$T = k \frac{s(E_2^{/})^2 R_2^{/}}{(R_2^{/})^2 + (sX_2^{/})^2}$(12)

Hence $E_2^{/}$is proportional to the applied voltage, and torque is proportional to the square of the applied voltage, and K is a constant. If K = $3/_{2\pi Ns}$ then the starting torque equation can be written as;

$T_{st} = \frac{3}{2\pi Ns} \frac{s(E_2^{/})^2 R_2^{/}}{(R_2^{/})^2 + (sX_2^{/})^2}$(13)

The method of speed control of induction motor majorly include; Pole changing, variable supply voltage control, variable supply frequency control, variable rotor Resistance control, volt/hertz (V/f) control, vector control, and slip Recovery. However, from the control methods mention above, the V/f control method is considered the most popular and widely used for industrial and domestic application. Meanwhile, it is obvious that the V/f method has inferior dynamic performance when compared with the vector control method, but can be effectively used inareas requiring precision. In [12], the implementation of the V/f and scalar speed control method of induction motor was carried out, it is a fact that, this technique can be achieved by controlling the frequency and amplitude of the stator voltage, making V/f to be constant. However, using a close loop control with a proportional control gives a better option to controls the speed of the motor at steady maximum torque, [13]. Comparing scalar and vector method, it is observed that, both have advantages and disadvantages, but that the scalar control method is cheaper and can easily be adapted with industrial control technique, [14]. The scalar control method is based on varying two parameters simultaneously. And in [15], the ratio of these two parameters is kept constant, and the torque produced by the induction motor remain constant at all range of speeds. The direct torque control(DTC) strategies using the pulse with modulation (PWM) inverter supply to ac motor have been proven to be an alternative when compared with the field oriented control (FOC), [16].

The adaptive technique such as PI controller and V/f scalar, is modelled and simulated. The PI controller is considered the most common approach for speed control of induction motor in industry. This is due to its simplicity and low cost, it also improves the dynamic response of the system and reduced the steady state error. However, this can be achieved by providing a proportional gain (K_P) and the integral correction component (K_i) using the feed forward path. The conventional block diagram model of the PI controller is shown in figure 6 below.

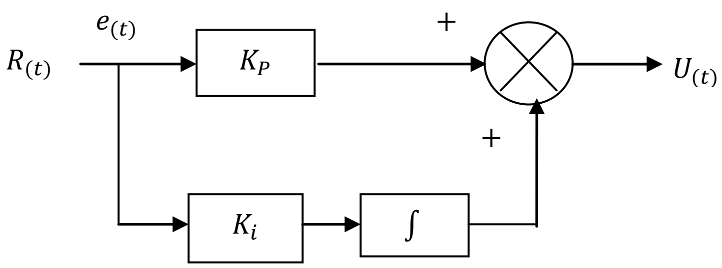

Figure 5: PI controller block diagram.

The output equation is obtained as shown in equation 14 below.

$U(t) = K_P e_{(t)} + K_i \int_0^t e_{(t)} dt$ (14)

Where(t), $U(t)$, is the input and output of the PI controller, and $e(t)$ is the error signal.

The integration of power electronic in induction motor speed control method is becoming more popular for industrial and domestic application.The space vector pulse width modulation (SVPWM) method is an advanced, pulse width modulation (PWM) technique and or method which are considered the best among all the PWM technique for variable frequency drive application, hence (SVPWM) generates less harmonic distortion in the output voltage and or current, that is applied to the three phase of an induction motor, [17].However, the (SVPWM) inverter technique can be implemented as shown in figure 6. The analysis of a 3∅ induction motor fed by pulse width modulation voltage source inverter regarding the phase current of the stator and rotor, torque and speed performance can be simulated. [18] Assert: the need for speed torque control of induction motor is very important in the modern day industrial operation.

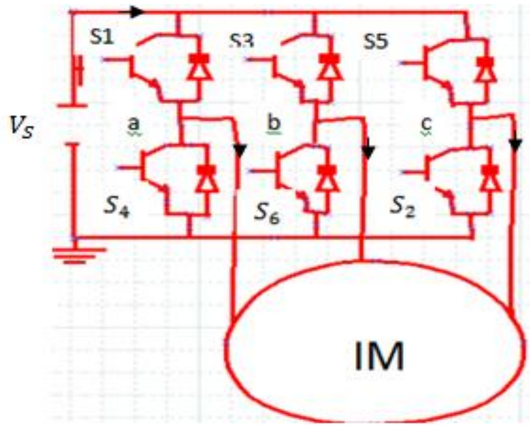

Figure 6: Induction motor voltage source inverter

The induction motor voltage source invertercircuit of figure 6 above is a three phase bridge topology consisting of a 3- half bridge legs, where each leg feds the respective phase of the induction motor drive. The voltage source (Vs) is a dc source connected across the three leg of the inverter. The circuit is arranged such that each inverter leg can synthesize two level voltages Vs and 0, at the inverter output terminal a, b and c, considering inverter leg a, if S_1 is ON and $S_4$is OFF, then the line voltage V_{an}, = V_S, also, if S_4 is ON, then S_1 will be OFF, and V_{an} = 0. WhenS_1, S_3 and S_5 is at the ON state, (Logic 1), it correspondingS_4,S_6, and S_2 will be on the OFF state, (Logic 0). However, at normal state, there are eight possible switching state of the inverter, as shown in table 1 below. Meanwhile, among the eight voltage vectors, the (0 0 0) and (1 1 1) logic are known as the zero vectors, while the remaining six that is (001), (010), (011), (100), (101), (110), are called the active vectors. More so, the ON and OFF states of transistorsS_1, S_3, S_5 in the odd or upper half of the inverter is used to determine the output voltage of the inverter.

Table 1: Switching vector and corresponding voltage level

Voltage vectors	Switching vectors	Switch ON state	Switch OFF state	Phase Voltage V_{LN}			I_{dc}
				V_{an}	V_{bn}	V_{cn}	
V0	000	S_4,S_6,S_2	S_1,S_3,S_5	0	0	0	0
V1	100	S_1,S_6,S_2	S_4,S_3,S_5	$\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	$+i_a$
V2	110	S_1,S_3,S_2	S_4,S_6,S_5	$\frac{1}{3}$	$\frac{1}{3}$	$-\frac{2}{3}$	$-i_c$
V3	010	S_4,S_3,S_2	S_1,S_6,S_5	$-\frac{1}{3}$	$\frac{2}{3}$	$-\frac{1}{3}$	$+i_b$
V4	011	S_4,S_3,S_5	S_1,S_6,S_2	$-\frac{2}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$-i_a$
V5	001	S_4,S_6,S_5	S_1,S_3,S_2	$-\frac{1}{3}$	$-\frac{1}{3}$	$\frac{2}{3}$	$+i_c$
V6	101	S_1,S_6,S_5	S_4,S_3,S_2	$\frac{1}{3}$	$-\frac{2}{3}$	$\frac{1}{3}$	$-i_b$
V7	111	S_1,S_3,S_5	S_4,S_6,S_2	0	0	0	0

Table 1 above shows also the relationshipbetween the active vector and phase current as measured dc sensor. It is obvious that atall instant, one of the phase currents relate to the dc link current.The relationship between the switching variable vector and the phase voltage vector can be express in matrix form as shown below.

$$\begin{pmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{pmatrix} = \frac{V_{DC}}{3} \begin{pmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} \qquad (15)$$

The proportional integral (PI) controller is used mostly for systems that control the speed motor, due to its low cost, simple to use and easy to design. However, PI parameters have difficulty determining their best valves. Meanwhile, the Ziegler-Nichols and Cohen-coon technique is used to find PI best parameters, [22; 23]. However, these methods are difficult and have unsatisfactory results and depend on knowing the mathematical model of the plant. The PI controller can be achieved by providing a proportional gain (Kp) and the integral corrections component or gain (Ki) using the feed forward path.

The fuzzy logic controller is a control technique that is based on linguistic control strategy, derived from expert knowledge into an automatic control strategy, [24].

The fuzzy logic control is a technique that embody human-like thinking into a control system, [25]. Fuzzy logic control is applied primarily to control processes though fuzzy linguistic analysis [26].stipulated by membership function, however, FLC is used for the designs of controllers for plants with complex dynamics and high non-linearity model. The fuzzy logic controller as used in motor control system is to convent linguistic control rules into control strategy based on heuristic information or expert knowledge. Their approach, is considered useful for induction motor drives, hence no exact mathematical model of the motto or the closed-loop system is required, [27] the fuzzy logic control, was first introduced by lofti A. Zadeh in 1965, the conventional Boolean logic has been extended to deal with the concept of partial truth value that exist between “true and false” which is refers to as fuzzy logic, this is achieved using the concept of the degree of membership. The fuzzy logic is developed is based on a set of linguistic “IF – THEN rule, like a human operator.

IV. Simulation results and Discussion

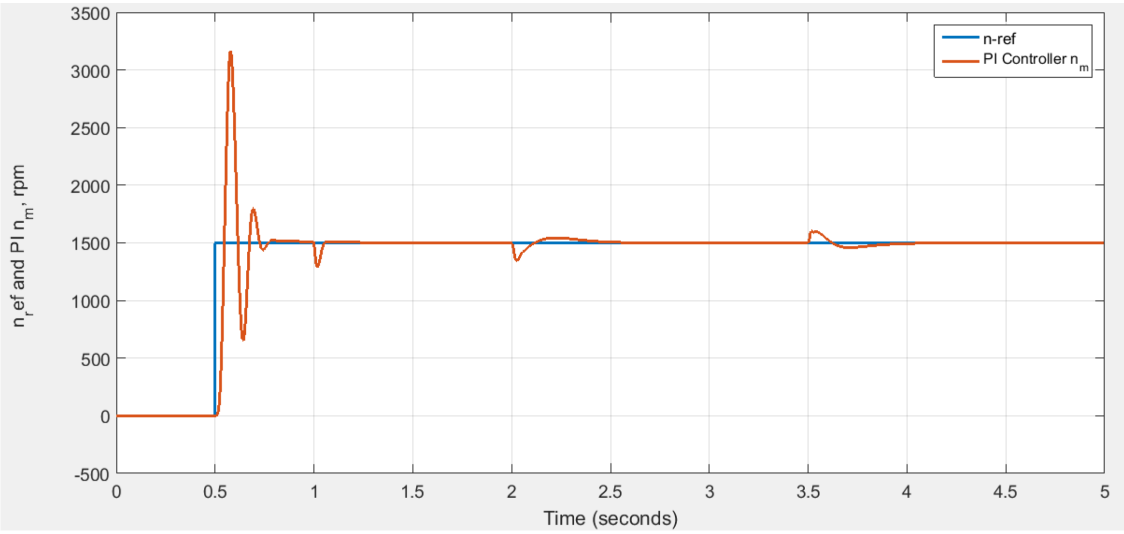

Figure 7: PI Speed Controller at different load tracking

The PI speed controller was set at 1500rpm with a load torque of 5Nm in 0.5sec, 1 sec, 2 sec, and 3.5 sec. the controller response is better hence it minimise the transient period.

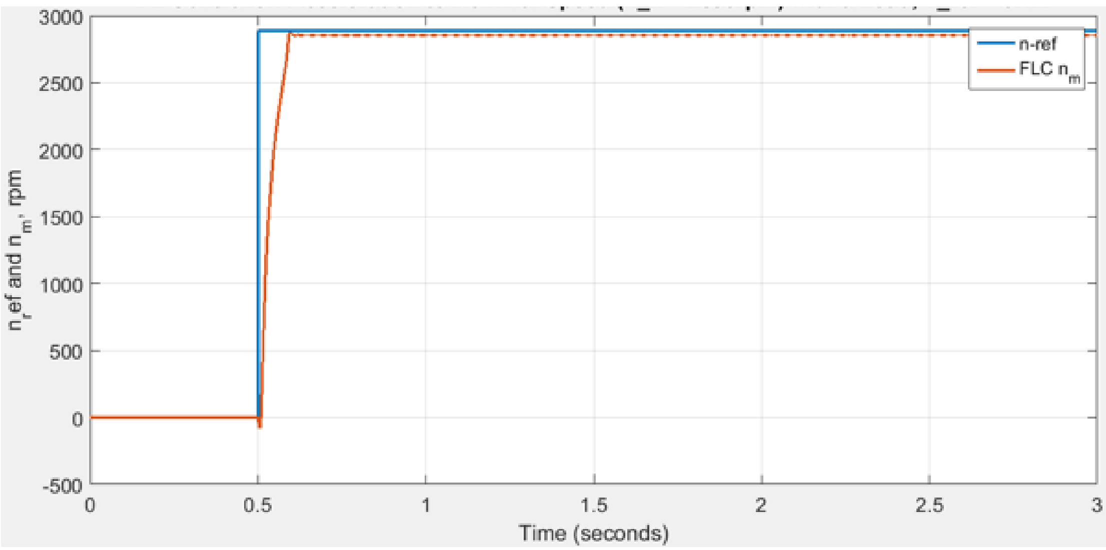

Figure 8: FL controller, acceleration to nominal speed of 2890 rpm with load torque of 5 Nm

The Fuzzy logic controller, as emulated in the speed controller was set at 2890 rpm with a load torque of 5Nm, in 0.5 sec, 1.5 sec, and 2.5 sec. the response shows a perfect results, indicating that the Fuzzy logic controller response quickly to load change without oscillation.

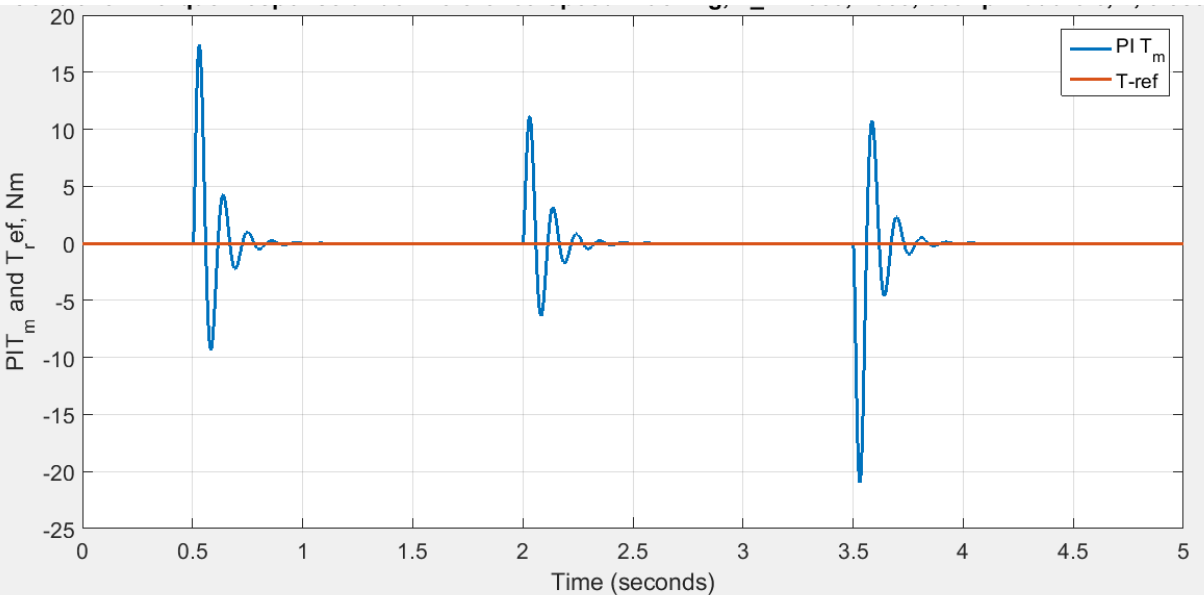

Figure 9: PI Controller, torque response at different load tracking

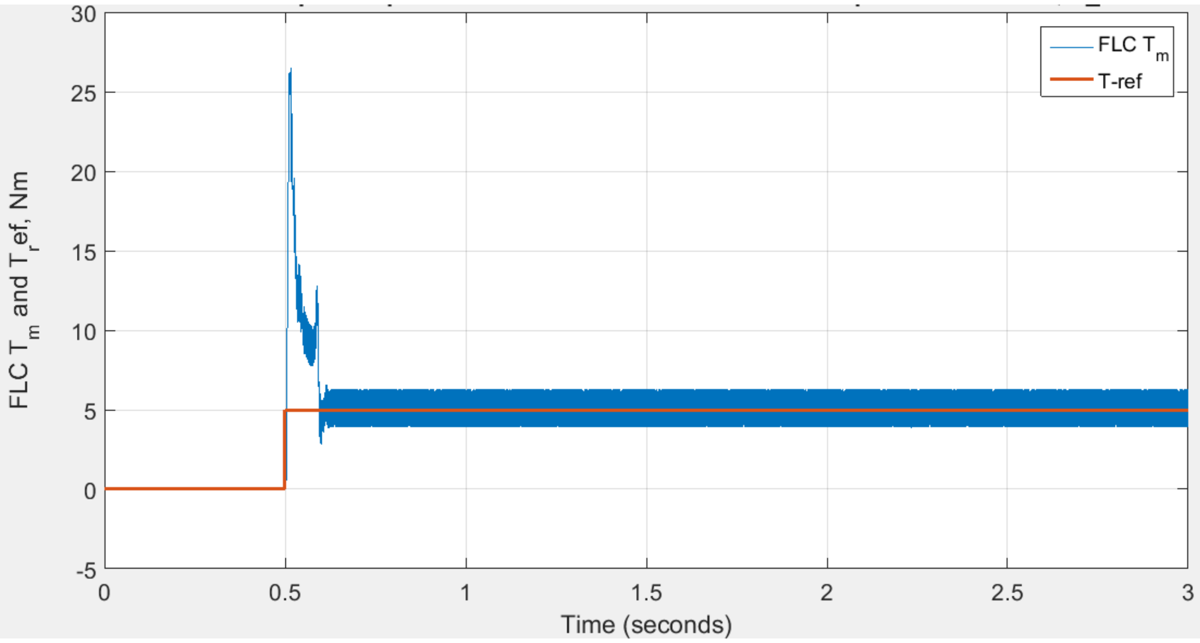

Figure 10: FL Controller, torque response with a load of 5Nm

V. Discussion/Recommendation

The induction motor survey as carried out in this paper work, shows that rotor excitation is induced from the stator field, which then required an asynchronous rotor speed to enhanced torque production. The V/f control scheme scalar control method is based on the steady state principle where only the magnitude and frequency are controlled, and not the space vector orientation. However, an approximately constant stator flux will result if the terminal voltage magnitude is proportional to the frequency. Meanwhile, the instantaneous voltage position, current and flux space vector are controlled by the vector control method. This paper from all survey recommend that the space vector pulse width modulation (SVPWM) method an advanced, pulse width modulation (PWM) technique and or method which are considered the best among all the PWM technique for variable frequency drive application, which generates less harmonic distortion in the output voltage and or current, that is applied to the three phase of an induction motor, should be incorporated. The performance analysis shows that the simulation result using fuzzy logic controller proves better when compare to PI controller.From the analysis, the PI controller was observed with high overshoot and large pulsation in torque which result in speed oscillation and long settling time. However, the fuzzy logic based drive controller has no overshoot in torque.

VI. Conclusion:

This paper survey induction machine control methods, the focus is the common V/f using fuzzy logic and PI to control induction motor (speed torque) control. The investigation of these methods shows that the scalar and vector control have advantages and disadvantages but that the scalar method is more advantageous in terms of cost, simple and resistance to feedback signal error. The IFOC as investigated shows that it can be controlled using the PI controller that is capable to improve the system dynamics and reduce steady state error. However, thePWM techniques among others were incorporated.However, the fuzzy logic based controller as comparedto the PI yield a better results.

References

[1]. Jay Patel, R. and Vyas, S.R. "Simulation and Analysis of Constant V/F Induction Motor Drive", International Journal of Engineering and Technical Research (IJETR), Volume -2, Issue 4, pp. 151-156, April 2014.
[2]. Sen, P. C. "Electric Motor Drives and Control Past Present, and Future", IEEE Transactions on Industrial Electronics, Vol.37, No.6, 562-575, 1990.
[3]. Bose, B. K., "Modern Power Electronics and AC Drivers",Prentice Hall, New Jersey, 2002.
[4]. Ho E.Y.Y. and Sen, P.C., "Decoupling Control of Induction Motor Driver", IEEE Transactions on Industrial Electronics, Vol.35, No.2, 253-262, 1988.
[5]. Santisteban, J. A. and, Stephan, R. M. "Vector Control Methodsfor Induction Machines: An Overview", IEEE Transactions on Education, Vol.44, No.2, 170-175, 2001.
[6]. Blaabjerg, F., Lungeanu, F. and Skaug, K. (2004). Two-phase induction motor drives, [online] https://ieeexplore.ieee.org/document/1311160/authors, Available at: https://www.bing.com/cr?IG=89010467723E4AC88D790B4C87831405.
[7]. Semiconductor, F. "3-Phase AC Motor Control with V/Hz Speed Closed Loop Using the 56F800/E," 2004.
[8]. Santisteban, J. A. and, Stephan, R. M., "Vector Control Methods for Induction Machines: An Overview", IEEE Transactions on Education, Vol.44, No.2, 170-175, 2001.
[9]. *NEMA Standards Publication,(2007). Application Guide for AC Adjustable Speed Drive Systems, Rosslyn, Virginia US: NEMA.* P,6.
[10]. Krause,P. C., Wasynczuk, O., Sudhoff, S. D. "Analysis of Electric Machinery and Drive Systems", IEEE Press, A John Wiley & Sons. Inc., Publication Second Edition, 2002.
[11]. Pabitra Kumar Behera, Manoj Kumar Behera, Amit Kumar Sahoo," Speed Control of Induction Motor using Scalar Control Technique", International Conference on Emergent Trends in Computing and Communication,(0975 – 8887), ETCC-2014.
[12]. Riya Elizabeth Jose, Maheswaran K.," V/F Speed Control of an Induction Motor Drive Fed by Switched Boost Inverter", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 4, Issue 8, August 2015.
[13]. Menghal, P. M., Jaya Laxmi, A., "Dynamic Modeling, Simulation & Analysis of Induction Motor Drives", International Conference on Science, Engineering and Management Research, 2014.
[14]. Kohlrusz, G., Fodor, D. " Comparison of Scalar and Vector Control Strategies of Induction Motors", Hungarian Journal of Industrial Chemistry Veszprém Vol. 39(2) pp. 265-270 (2011).
[15]. Buja G.S., KazmierkowskI M.P.: 'Direct torque control of PWM inverter – fed AC motors', IEEE Trans. Ind. Electron., 2004, 51, (4), pp. 744–757
[16]. Hanan Mikhael, D. H., Hussein, J.A., Inaam I.A. (2016), 'Speed Control of Induction Motor using PI and V/F Scalar Vector Controllers'International Journal of Computer Applications (0975 – 8887) Volume 151 – No.7, (2016),
[17]. Devraj Jee, Nikhar Patel, 2013, "V/F Control of Induction Motor Drive", MSc Thesis, National institute of Technology, Odisha
[18]. Jay R. Patel and S.R. Vyas "Simulation and Analysis of Constant V/F Induction Motor Drive", International Journal of Engineering and Technical Research (IJETR), Volume -2, Issue 4, pp. 151-156, April 2014.
[19]. Zwe-Lee Gaing (2004). "A Particle Swarm Optimization Approach for Optimum Design of PID Controller in AVR system," IEEE Transactions.
[20]. Jarnal Abd Ali, Hannan M.A, and Azah Mohammed, (2016), "Control of induction motor drive based PSO Algorithm," Jurnal Teknologi, Vol. 78, No. 62, Pp27 – 32.
[21]. Zimmermann, H. (2001), "Fuzzy set theory and its applications," Boston Kluwer Academic Publishers. ISBN 0-7923-7435-5.
[22]. Kotyada, A.D, Kalyani, B. Shanka, P. (2012) "Efficiency Optimization control of Induction motor using Fuzzy logic "International Journal of soft computing and engineering (IJSCE). ISSN:2231-2307, Vol. 2. Issue 3.
[23]. Singh, C. and Sarkar, D. (1992), "Practical consideration in the optimization of inducting motor design" IEEE Proc. B. Vol 139, No.4
[24]. Kouzi, K, Mokrani, M.L and Naik said S. (2003) "A new design of fuzzy logic controller with fuzzy adapted gain based on induction vector control for induction motor drive". IEEE

Akpama, E. J, et. al. "Induction Machine Speed Control: A survey." *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE),* 16(1), (2020): pp. 30-37.