Scalar Control Dynamic Simulation of Induction Motor Using Simulink

Eko J. Akpama, Emmanuel. E.Effiong, Iwara. E. Omini, Raymond. U. Ezenwosu

Abstract— **The three-phase induction motor is popular and widely used in industrial, commercial and residential loads. It has several inherent advantages like low cost, reliability, rugged design, high robustness, high efficiency and low maintenance cost. This makes research in dynamic behaviour of the induction motor very useful. This motor characteristics are suited for variable speed drives. In this paper a constant v/f scalar control is employed for close loop speed control of induction motor that is fed with pulse width modulation voltage source inverter. The machine is simulated using MATLAB/SIMULINK software. The transient performance of the machine is analyzed in term of speed, electromagnetic torque and stator current responses. The Fuzzy logic controller simulation results are compared to that of conventional PI controller results. Fuzzy logic controller offers faster response of machine**

Index Terms— **Constant V/F control, Voltage source Inverter (VSI), Fuzzy logic controller (FLC).**

I. INTRODUCTION

In modern days, the application of induction motors in speed and position-controlled drives has been on increase. The induction motors are used as actuators in varied industrial processes, robotics, and other similar applications, this motor are reliable than dc motors. To obtain high static and dynamic qualities of ac drives, Control Engineers need more information about the control objective, so it is important to determine the characteristics and parameters of induction motors [1]. The induction motor dynamic characteristics of its transient behaviour is simulated with simulation software like Pspice, MATLA/SIMULINK, PSIM software [2]. The non-linear nature of the induction motor control dynamics requires cumbersome control algorithm for the control of speed. Common controllers used include proportional integral (PI), Proportional Derivative (PD), Proportional Integral Derivative (PID), fuzzy logic controller (FLC) or a blend between them.[3]. FLC is a control of algorithm based on a linguistic control strategy which is derived from expert knowledge. Since most important challenge is to reduce the motor power consumption, by varying the shaft speed of motor as there are designed as constant speed machine. Motor efficiency can be increased by obtaining best transient response using constant v/f technique and FLC optimize efficiency of motor [4][5]. The machine parameters are developed in m-file for simulation.

II. FUZZY LOGIC CONTROLLER DESIGN

The design of FLC require definition of input variables which are;

(i)Speed error (e)

(ii)Change in error or derivative of speed error (Δe)

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The speed error is expressed as;

$$e = \omega_{ref} - \omega_m \quad (1)$$

$$\Delta e = \frac{de}{dt} \quad (2)$$

The controller output called change in control is $\omega_{sl.}$ the 49 rule is saved with extension.FIS.

III. SCALAR V/F CONTROL DESIGN

The actual motor speed in radians per second is obtained from r.p.m value as

$$\omega_m = \frac{2\pi\ Nm}{60} \quad (3)$$

The actual motor speed or rated speed of motor is

$$N_m = (1\text{-}S)Ns \quad (4)$$

The synchronous speed of motor is express as

$$N_s = \frac{120f}{p} \text{ in revolutions per minutes (rpm)} \quad (5)$$

Where P= number of poles, f=supply frequency of input power to motor.

ω_s = angular synchronous speed,

$$\omega_s = 2\pi N_s \quad (6)$$

The slip,

$$s = \frac{\omega s - \omega m}{\omega s} \text{ in percentage} \quad (7)$$

All variable Frequency Drive (VFD) maintain the output voltage to frequency V/F ratio constant throughout the speed range according to equation (8) in order to maintain constant magnetic flux in air gap of induction motor.

$$\frac{V}{F} = 4.444N\,\phi_m \quad (8)$$

Where V is supply voltage into the motor, F is supply frequency, ϕ_m is the peak air gap flux and N is the number of turns per phase in stator. Since N is constant, the flux is kept constant as the V/f ratio is constant.

The input to scalar block is the synchronous frequency (ω_{synch}).

$$\omega_{synch} = (\ \omega_m + \ \omega_{sl.}\ ) \quad (9)$$

Where ω_m is the actual motor or rotor speed, $\omega_{sl.}$ is the slip speed from controller

The three sinewave blocks or modulating signal amplitude of scalar control block is derived from gain (k) which maintain the constant dc voltage to synchronous frequency ratio

The K expression is

$$K = \frac{Vdc/2}{\sqrt{2}\,\omega_*} = \frac{Vdc}{2\sqrt{2}\,\omega_*} \quad (10)$$

Where $\omega_* = 2\pi f$ (11)

The angle θ of the three modulating signals is obtained by integrating the synchronous frequency $\omega_{synch.}$ That enters the scalar control block, where f is nominal motor supply frequency(50Hz)

$$\theta = \int \omega_{synch.} \, dt \quad (12)$$

Carrier signal block has amplitude is expressed as

$$A_c = \frac{Vdc}{2} \quad (13)$$

Where V_{dc} is the inverter in dc input voltage and its divided by two since inverter used has split dc source And the Carrier (triangular or sawtooth) signal frequency is set at 4 KHz

As the three sinewave or modulating signal is compared with carrier signal by using relational operator block from Simulink library, this perform sinusoidal pulse width modulation and the necessary bipolar pulses are generated from this scalar v/f control block output which turn on the three phase inverter switches (IGBT, MOSFET).

The SPWM Inverter output phase-voltage with variable frequency has rms value expressed as

$$V_o = \frac{M * Vdc}{2\sqrt{2}} \quad (14)$$

The three-phase line- line voltage of inverter feeding the Induction motor stator is expressed as

$$V_{o\ rms} = \frac{\sqrt{3} * M * Vdc}{2\sqrt{2}} = 0.612 * M * Vdc \quad \text{in Volts} \quad (15)$$

$$M = \frac{A_m}{A_c} \quad (16)$$

Where M is amplitude modulation index, A_m is amplitude of reference modulating signal or sinewave, M is 1.0 as both A_m and A_c has same amplitude given in (13) ,Vdc=660v, $V_{o\ rms}$ =403.9V from (15).

The inverter gain is the value $\frac{M}{2\sqrt{2}}$

The torque developed in air gap is given as

$$T_m = \frac{3 * (Ir)^2 * Rr}{2 * \omega m * s} \quad (17)$$

$$T_m = \frac{PN}{\omega_m} \text{ in Nm} \quad (18)$$

where PN is machine rated power in Watts, Ir, Rr, are rotor current and rotor resistance.

Mechanical developed torque varies as the square of applied voltage to its stator terminals. By varying voltage, the torque can be varied. when the rotor frequency is equal to synchronous frequency the torque is zero.

IV. SCALAR V/F CONTROL OPERATION IN FEEDBACK SYSTEM

The closed loop scalar controller is designed to operate such that when a reference (desired) speed value is set, the controller evaluates the speed error. The feedback technique provides synchronous frequency to scalar V/f control block which generate switching pulses for inverter power switches, the SPWM voltage source inverter (VSI) supply variable frequency voltage to the three-phase induction motor, and motor run at speed that equal reference speed. And once a new speed value is set, the controller evaluates the error as the scalar block provides the required switching pulse signal to inverter and VSI in provides the voltage with required frequency to motor stator, and the motor run at the speed that matches the reference or command speed value.

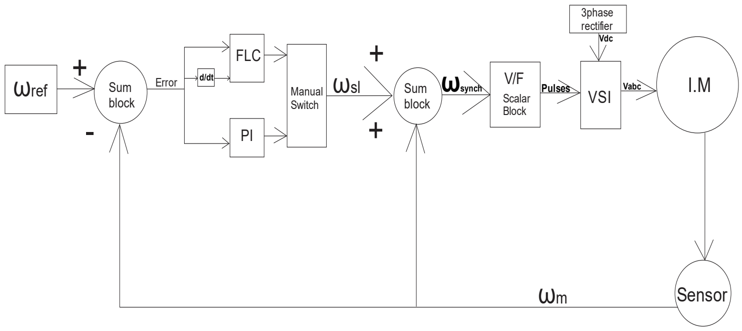


Figure 1. Block diagram of the speed control system

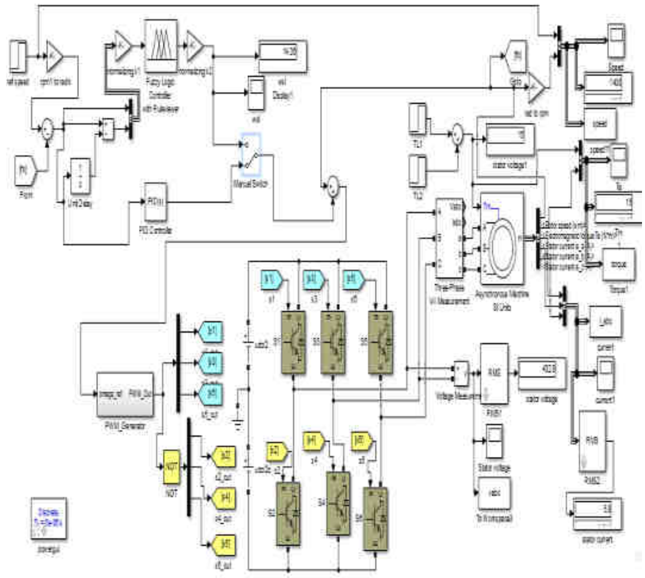


Figure 2. Complete SIMULINK diagram of the speed control system for induction motor.

Table 1 **MACHINE DATA**

Power	4	Kilowatt (KW)
Voltage	400	Volts (V)
Frequency	50	Hertz (Hz)
Rated torque	26.7	Newton-meter (N-m)
Rated speed	1430	Revolution per minute(rpm)
Stator resistance	1.405	Ohms (Ω)
Stator inductance	0.005839	Henry (H)
Rotor resistance	1.395	Ohms (Ω)
Rotor inductance	0.005839	Henry (H)
Mutual inductance	0.1722	Henry (H)
Poles	2	
Moment of inertia	0.0131	Kg. m^2
Kp	0.6	
Ki	3.0	
Kd	0	

V. SIMULATION RESULTS PRESENTATION AND DISCUSSION

The simulation results obtained from the complete SIMULINK control system block diagram in figure 5. The

simulations were carried out using MATLAB/ SIMULINK software
using a 3hp,400v,1430rpm,50Hz squirrel cage induction machine. After simulation, plots of speed, torque and stator current against time for fuzzy logic controller and also plots of the responses PI controller are shown blow;

speed response (ω_m =1400rpm)

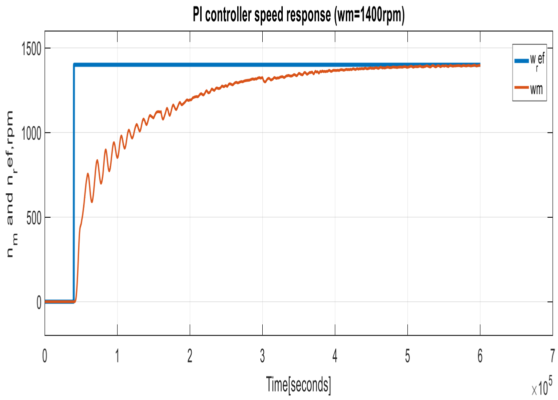


Figure 3 speed response using PI controller for ω_m =1400rpm)

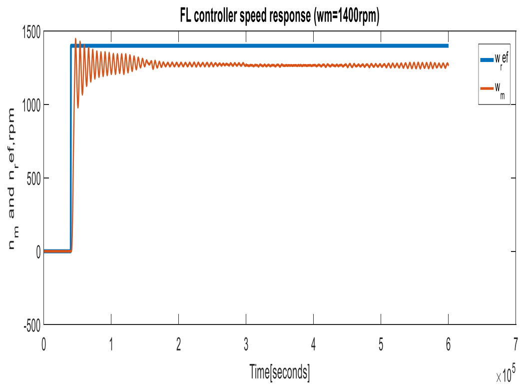
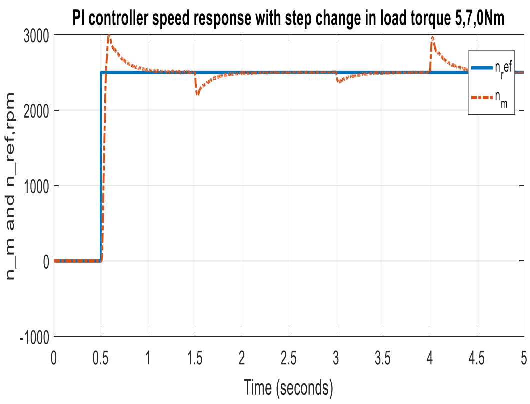


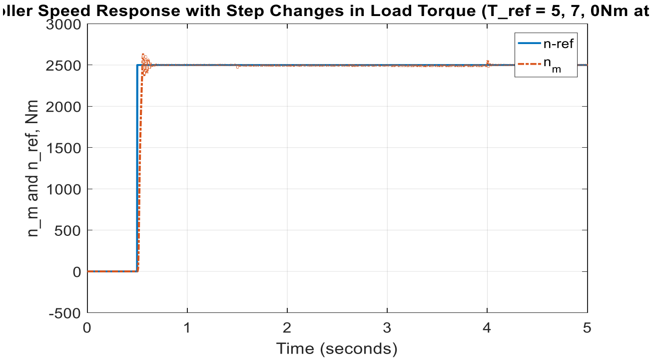
Figure 4 speed response using FL controller for ω_m =1400rpm)

The figure 3 and 4 show the speed response for PI and FL controller at reference speed of 1400rpm, in figure motor starts at 0.2 second and the motor speed tracks the reference speed after 4seconds. While in figure7, the is steady state error as motor run at 1300rpm but settling time is faster which is 1.6 second.

Speed response with step change in load torque



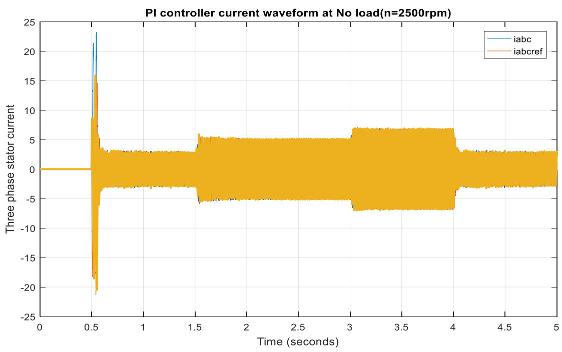
(a)PI



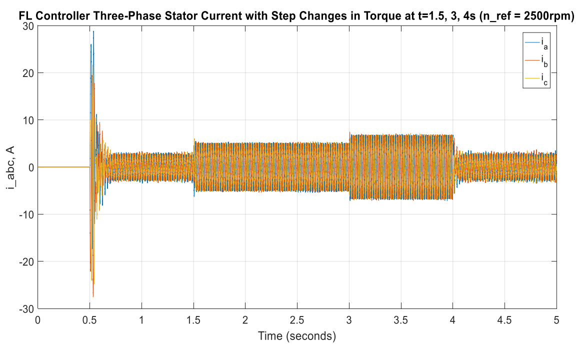
(b) FLC

Figure 5 speed versus time response with step change in applied load torque for ω_m = 2500rpm
Motor as it run at reference speed of 2500 rpm with step change in torque. At 0.5second motor start running and at 1.5 second a load of 5NM is applied then after 3seconds 7NM is applied and load torque was removed at 4seconds. It is noticed that when running the motor with PI controller, there is a significant drop in motor speed value(2370rpm) at 1.5second as load torque of 5NM is applied. Similar drop in speed (2200rpm) was observed at 3seconds when the load torque increase to 7Nm). And at 4seconds when load torque was removed, speed significantly increased to 2700rpm and finally settled to desired steady state value of 2500rpm after 0.8second. FLC showed high level of robustness as the close loop control system cancel out the disturbance effect within 0.16second at all instances of step change in load torque which is almost unnoticed compared to that of PI controller.

stator current waveform with step change in load torque



(a)PI



(b)FL

Figure 6 stator current versus time plot for step change in load torque at reference speed (2500rpm).
The magnitude of current envelope increased as applied load torque increased. its highest at load torque of 7NMs.after 3

seconds and at 4seconds when load torque was removed, its magnitude decreased to its initial value at the start of motor. FLC shows similar waveform, the amplitude of stator current waveform increased when load torque was applied, and later decreased to at 4seconds when load torque as removed.

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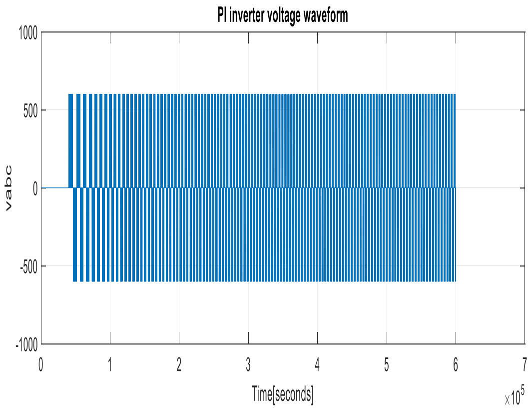

Figure 7 SPWM voltage source Inverter output line-line voltage waveform.

CONCLUSION

This paper presents development and simulation of three phase induction motor speed control model in MATLAB/ SIMULINK software and scalar v/f control method is employed. The simulation was carried out and the transient behaviour of the induction motor is obtained for PI controller and FL controller. The rotor speed, electromagnetic torque and stator current responses of the machine is plotted with time. FLC showed faster transient response of speed control system and robustness to change in load condition. The performance measure like rise time, settling time, maximum overshoot and steady state error was evaluated and FLC showed better performance to that of Conventional PI controller. The author believes that the simulation of speed control system of induction motor model will be useful tool for research and Teaching of electrical machine drives and other speed control system applications.

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