

## PERFORMANCE EVALUATION OF FUZZY LOGIC CONTROL OF INDUCTION MOTOR

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### ABSTRACT

Speed control of induction motors has been a challenge mostly during industrial processes. These motors are used to carry out different task at different speeds. A three phase induction motor is a constant speed motor; therefore, it is difficult to control its speed especially maintaining a constant speed with load variation. There is a tradeoff in efficiency and power factor when the speed of the motor is being controlled. Different methods of speed control have been proposed and used with their attended advantages and disadvantages. In this paper, Fuzzy logic is used to control the speed of an induction motor under load variation. The control architecture includes some defined fuzzy rules, which portray a nonchalant relationship between the two inputs; *speed error* ( $e$ ) and *change in error* ( $\Delta e$ ), and the output *frequency or change in control* ( $\omega_{sl}$ ). The errors are evaluated according to the rules by the defined member functions. The system model is simulated in MATLAB/SIMULINK and the simulated results presented. The results obtained using a conventional PI controller and the designed Fuzzy Logic Controller has been studied and compared. The FLC presents better performance in terms of stability, precision and reliability when compared to the PI.

**KEYWORDS:** Fuzzy logic, Speed control, Proportional integral controller, induction motor.

### INTRODUCTION

The induction motor is indispensable in the industry, the workhorse in industrial processes and controls. In years past, dc motors were predominantly used in this regard due the

challenge of speed control in induction motors. The emergence of AC drives (power electronics) has made induction motors more popular because today speed control in induction motors is possible and easy, notwithstanding other benefits of induction motors compared to dc motors. Generally, variable-speed drives for induction motors require wide operating range of speeds and fast torque response, regardless of load variation, and acts as industrial energy savers. Voltage source inverter-fed induction motors are most preferred for variable speed drive applications. Recorded advantages of Induction motor includes; Simple and rugged design, No brushes, Low maintenance cost, high efficiency and ability to operate in hazardous environment. Induction motors have the following demerits; (a) Load is dependent on slip, (b) Position sensor may be required, and (c) it is a fixed-speed motor. Due the above, developing a control system for induction machine operation becomes imperative.

It is a known fact that, speed control is one of the imposed constraints in induction motors. In the last decades, studies in this direction have created more research interest and various methods of controls have been developed.<sup>[1,2]</sup> Induction motor speed can be controlled from either the stator or rotor circuits. If the control is from the stator circuit, then variables of interest could be; Volt/Hertz or frequency, stator poles, supply voltage.<sup>[3]</sup> From the rotor circuit, adding external resistance, Cascade control method, or injection of slip frequency emf are options of speed control. The closed loop volt/hertz control method is developed here to control the speed of a 7.5kW, three phase induction motor. To maintain a constant speed on load, Fuzzy Logic Controller (FLC) is introduced and the result is improved performance compared to that of a Proportional Integral (PI) controller. According to,<sup>[4,5]</sup> both Fuzzy Logic Controller (FLC) and Proportional Integral (PI) Controller are artificial intelligent method which has found high application in most of the non-linear systems like the electric motor drives. Fuzzy Logic Controllers (FLCs) are advantageous because they are economical, operate over ranges of operating conditions and they easily adapt to natural language.<sup>[6,7,8]</sup> It deals with reasoning that is approximate rather than fixed and exact. Compared to the traditional binary set, fuzzy logic variables may have a true value that ranges in degrees between 0 and 1<sup>[9,10]</sup> The FLC provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy.<sup>[11]</sup>

### **Stator Voltage and Frequency Control**

The Stator V/f control is carried out by varying the voltage to frequency ratio of the supply to the stator. If the ratio of voltage to frequency is kept constant, the flux will remain constants.

This will prevent the saturation of the air-gap flux due to increase in flux. By keeping the ratio of voltage/frequency constant, the motor delivers its rated torque at its rated speed.<sup>[6,7]</sup> In all the various speed control mechanisms, the volts/hertz control scheme is very popular because it provides a wide range of speed control with good running and transient performance also known as scalar control mode, where the input and output are speed, unlike the vector control mode where it is torque/flux as input and reference current as output. Voltage/frequency converters help to vary the speed over a wide range.

The conventional control methods have some demerits as listed below;<sup>[2]</sup>

- It depends on the accuracy of the mathematical model of the system,
- The expected performance is almost impossible due to motor saturation and thermal variation,
- Accurate performance is exhibited only at one operating speed when classical linear control is employed.
- Choosing the right coefficient with varying parameters like the set point is difficult because coefficient must be chosen properly for the expected result,
- To implement a conventional control methodology, it is necessary to have knowledge of the system's model that is to be controlled.

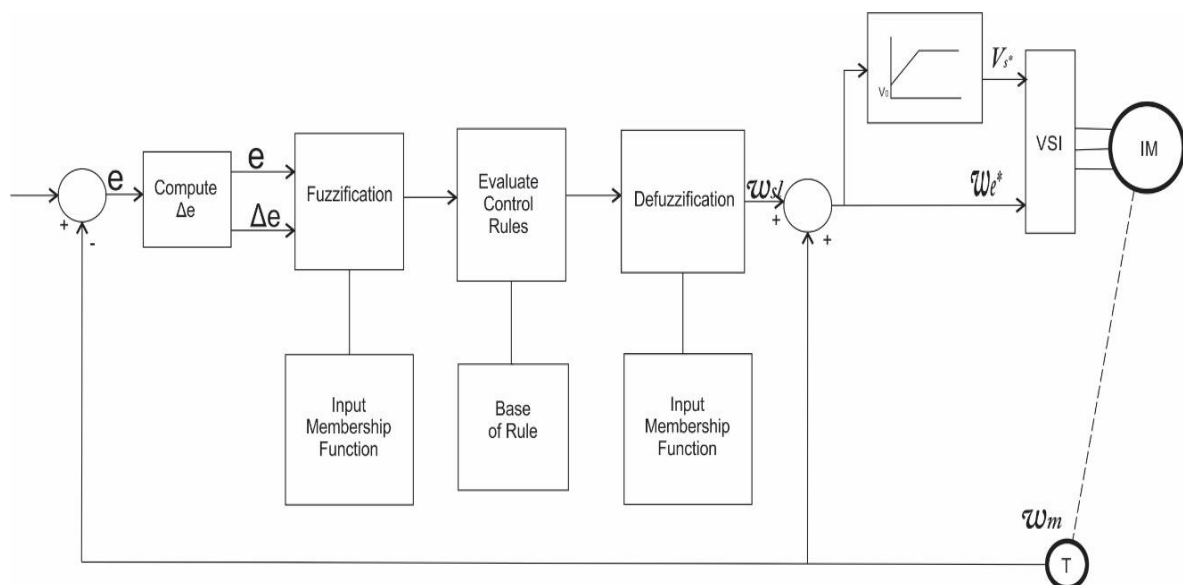
Due to the above, the design for high performance control becomes complex and very costly. Therefore, the proposal of an advanced control system based on artificial intelligence technique also called intelligent control and self-organizing system is imperative. The emergence of high power, high speed and low cost modern processors along with power technique switches like IGBT has made intelligent control a good potential in electric drives. Artificial intelligent techniques is categorized into; hard and soft computation.<sup>[1,12]</sup> Soft computation is used widely in electric drives system.

Therefore, to overcome the complexities of conventional controllers, FLC is designed and implemented in many motor control applications, owing to its knowledge based algorithm, better non-linearity handling features and impedance of the processed plant modeling. FLC owes its popularity to its linguistic control; it tries to replicate the human thought process in its control algorithm hence an exact mathematical model for the system to be controlled is not required. This allows intermediate values to be defined, conventional evaluations like true/false, yes/no, high/low etc.<sup>[5]</sup> In,<sup>[13]</sup> Zadeh initiated Fuzzy Logic in 1965.<sup>[2,3,4]</sup> The FLC

method has been proven to make good performance in terms of stability, precision and reliability. It takes two inputs which are; error ( $e$ ) and change in error ( $\Delta e$ ) to model a FLC with the help of IF-THEN rules with an added advantage of no complicated hardware.

### Speed Control of Three Phase Induction Motor

Figure 1, shows the block diagram of an induction motor speed controller. The frequency and supply voltage to the induction motor are varied such that it operates at steady state, and desired speed. The choice of speed as the reference signal is justified since the parameter of interest is speed. A feedback mechanism is used to provide the quality of automation to the control system. The instantaneous output signal is fed back to the system's input to achieve the desired output. Change-of-error is the derivative of speed error, and both errors ( $e$ ) and change-of-error ( $\Delta e$ ) are fed into the Fuzzifier. The inference system then processes these two fuzzy inputs using the fuzzy control rules and the database, which are defined based on the chosen membership function and fuzzy rule table, to give an output fuzzy variable. The Defuzzified output gives a scripts value which is the change-of-control of the system ( $\omega_{sl}$ ). This is then added to the motor speed ( $\omega_m$ ) which in turn forms the input to the Voltage Source Inverter and V/f controller.

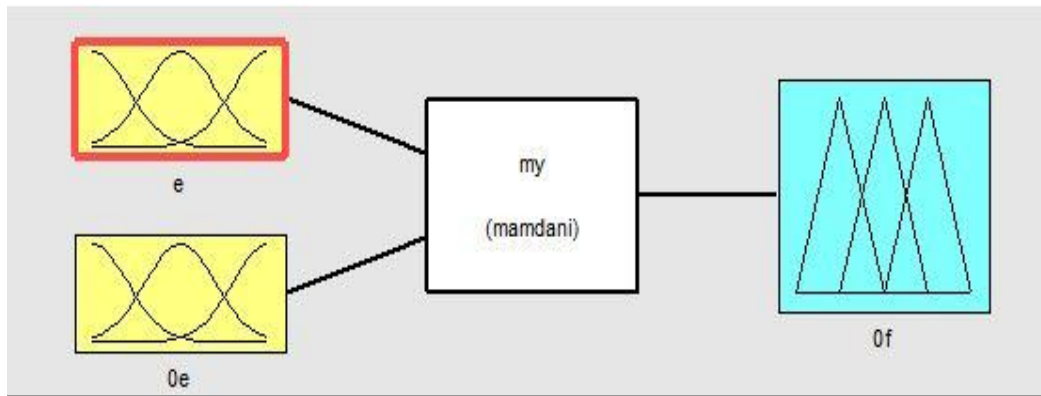


**Fig. 1: Speed Control system of Induction Motor using Fuzzy Logic Controller.**

The VSI receives voltage signal from the V/f controller and frequency signal to generate a three phase voltage whose frequency and amplitude can be varied by the Fuzzy Logic Controller. These Three phase voltages are then fed to the induction motor thus generating speed which tends to run with the desired speed (reference speed).

### Membership Function Design

The membership functions are designed for Error ( $e$ ), Change in Error ( $\Delta e$ ) and output ( $\omega_{st}$ ) as shown in figure 2. The linguistic label used in both the Error ( $e$ ) and the change in Error ( $\Delta e$ ) includes; Negative Large (NL,) Negative Medium (NM), Negative Small (NS), Zero (ZZ), Positive Small (PS), Positive Medium (PM) and Positive Large (PL). The linguistic label used for the output ( $\omega_{st}$ ) are, Negative Large (NL), Negative Medium (NM), Negative Small (NS), Negative Very Small (NVS), Zero (ZZ), Positive Very Small (PVS), Positive Small (PS), Positive Medium (PM) and Positive Large (PL).



**Figure 2: FIS Fuzzy Editor with 2 Inputs and 1 Output.**

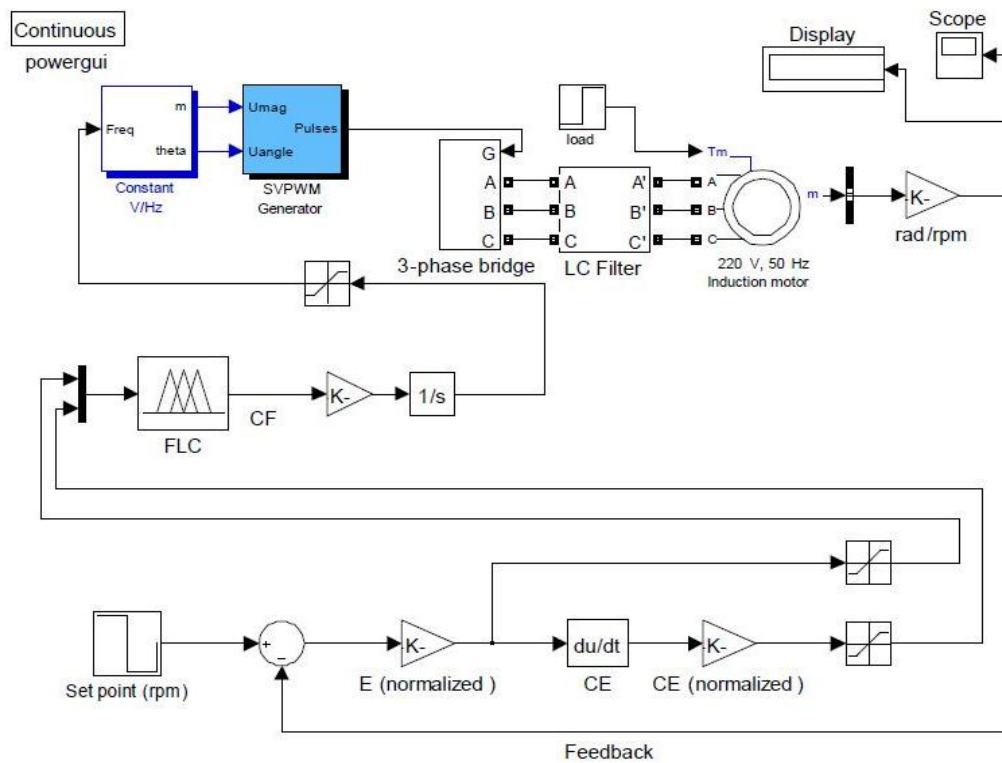
Membership Function of FIS showing Error, Change in Error and Output.

### Rule Base Design for Output

The Rule base for the decision making of the output of the inference system consists of 49 rules using the IF-THEN rule base. This output which is the change in error is added to the motor speed to give supply frequency which goes into the v/f block. The developed SIMULINK model is shown in figure 4 below:

**Table 1: Fuzzy Rule Table for Output ( $\omega_{st}$ ).**

$\Delta e$	NL	NM	NS	ZZ	PS	PM	PL
NL	NL	NL	NL	NM	NS	NVS	ZZ
NM	NL	NL	NM	NS	NVS	ZZ	PVS
NS	NL	NM	NS	NVS	ZZ	PVS	PS
ZZ	NM	NS	NVS	ZZ	PVS	PS	PM
PS	NS	NVS	ZZ	PVS	PS	PM	PL
PM	NVS	ZZ	PVS	PS	PM	PL	PL
PL	ZZ	PVS	PS	PM	PL	PL	PL

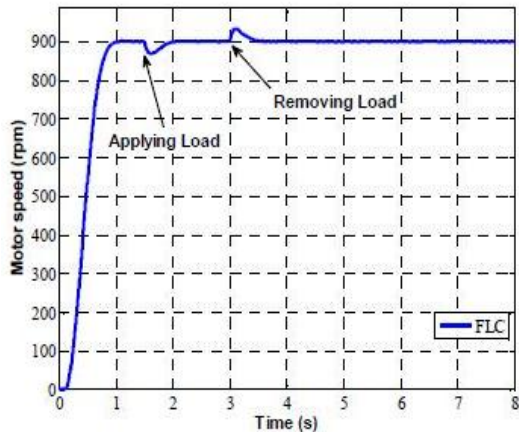


**Figure 3: SIMULINK Model of the Fuzzy Logic Controller.**

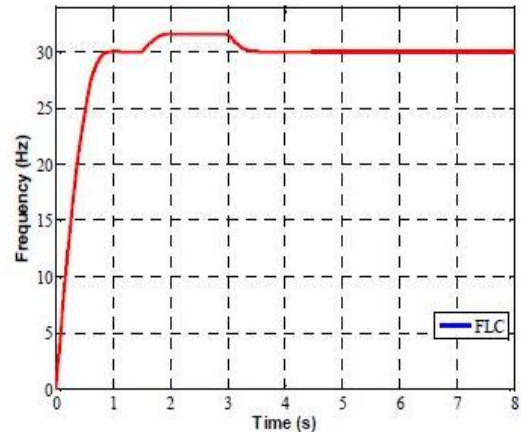
As shown above, set point is the desired speed of the motor, while the feedback signal is the measured value of the induction motor speed. The measured speed is multiplied by  $(30/\pi)$  to convert the (rad/s) unit into (rpm) unit. The error signal (which is the actual speed subtracted from the desired speed) and its derivative are used as input for FLC block. The output of FLC is the required change in frequency which will be integrated continuously, while the saturation block is used to limit the output frequency within the system limitations. The control signal, which represents the frequency in this case, is sent to V/Hz block which will maintain a constant ratio between voltage and frequency to keep the torque constant while the speed varies. The output of this block is sent to SVPWM generator which will accordingly produce a PWM signal that meets the input frequency. Resulted PWM signal is used to trigger the MOSFET Hex-bridge to produce a similar signal with amplified voltage in the inverter output.

### Simulation and presentation of Results

Several simulations were carried out on the PI and FLC controllers under different operating conditions of the induction machine. The performance of PI and FLC models with a little load disturbance by simulation are presented in the following figures.

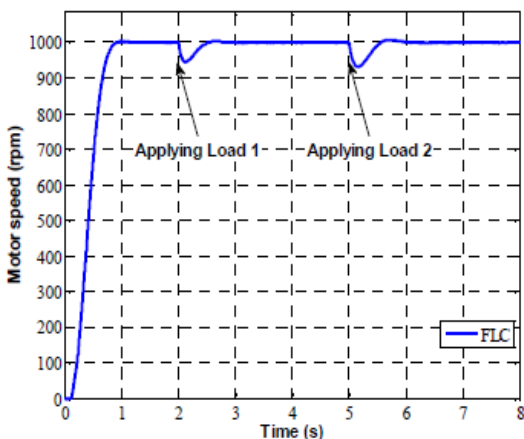


**Figure 4: Speed Response at 900 rpm.**

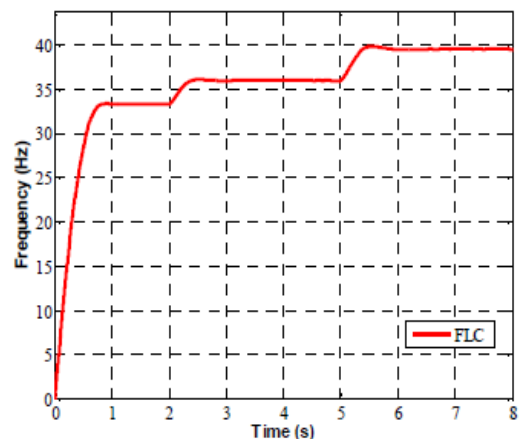


**Figure 5: Control Signal at 900 rpm.**

The speed response of the proposed control system when the reference speed = 900rpm, while the second shows the output of FLC (the control signal). In this simulation, a load was applied at time = 1.5s, then it was removed at time = 3s. The applied load caused the motor speed to go down below the reference speed. At the same time, the control signal went up to compensate the loss of speed. When the applied load was removed, the control signal went down to maintain the actual speed equal to the set point. Figures 6, 7, show the speed response of FLC system while applying two loads with time interval between them.

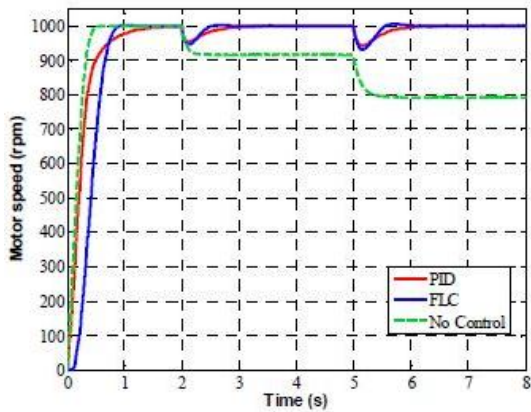


**Figure 6: Speed Response at 1000 rpm.**

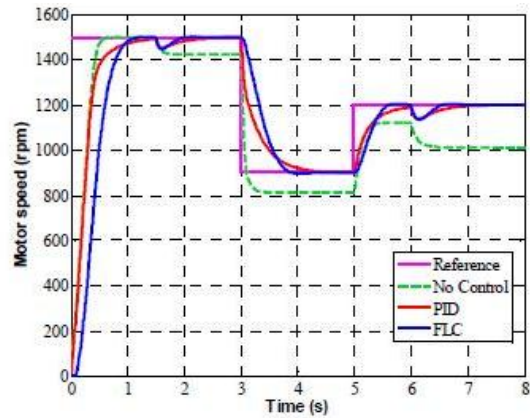


**Figure 7: Control Signal at 1000 rpm.**

As seen in the speed response at 1000rpm, load 1 was applied at time = 2 s, while load 2 was applied at time = 5 s. Since load 2 is greater than load 1, its effect on the motor speed is greater. Consequently, the control signal is proportional to load disturbance, the actual motor speed is maintained equal to the reference speed after a short time of change because of load disturbance. For comparison, the following simulation tests show the speed response of the system while using FLC and PI for various reference speed and applied load.



**Figure 8: Speed Response for Sudden Change of Load**



**Figure 9: Speed Response for Sudden change in Load and the Reference Speed.**

## DISCUSSION OF RESULTS

The simulation result is presented showing the performance of the machine with different controllers; without control, with PI and with FLC, with apply load at time = 2 s and another load at time = 5 s. The Multi-reference speeds; 1500, 900 and 1200 rpm were used with load disturbance at time = 3 s and at time = 5 s. As noticed in both figures, there is a sharp response to different loads as indicated, both PI and FLC showed a good response to this change. Table 2 shows the performance indices of FLC and PI, for of rise time and settling time, when multi-step speed input is applied.

**Table 2: Comparison of FLC and PI.**

Reference Speed (rpm)	Rise Time (s)		Settling Time (s)	
	FLC	PI	FLC	PI
<b>1500</b>	0.5392	0.4026	0.9496	0.9685
<b>900</b>	0.5387	0.6476	0.8074	1.1844
<b>1200</b>	0.3850	0.5201	0.5736	0.8461

It is clear from the results that, FLC showed better performance compared to PI controller. FLC also showed the ability to control speed of the three-phase induction motor and provide an accurate and fast response with relatively no overshoot and no steady state error.

## CONCLUSION

The speed of industrial motors are controlled for best performance, control of electric machine is one challenge operators have, mostly for induction motors with constant speed. Industrial loads most cases are variable and the motor speed should also be variable. Here different types of control methods were investigated, which revealed that the FLC showed a



better performance and faster response when compared with PI. A sample test was done using the following input speeds: 700, 900, 1200 and 1400 rpm, and the resulting THD was 2.3%, 2.9%, 1.8% and 3% respectively, which is less than 5%, the acceptable harmonic distortion as recommended by IEEE standards.

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