A Novel Strategy For Speed Control of A Direct Field-Oriented Induction Motor Drive Using PID Controller And Fuzzy Logic Technique

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Abstract- *This paper deals with a design of PID controller to control the speed of a Direct Field-Oriented Induction Motor (DFOIM) in par with the Fuzzy logic technique. The PID is adopted because its parameter values can be chosen using a simple and useful rule of thumb. The output of the PID controller is given to the FLC. The FLC is connected to the PID controller for enhancing robust performance in both dynamic transient and steady-state periods. In the phase- I, the design of a PID controller is to be made. The FLC is developed based on the output of the PID controller, and the output of the FLC is the torque command of the DFOIM. The complete closed-loop speed control scheme is implemented for the laboratory 0.14-hpsquirrel-cage induction motor. Experimental results demonstrate that the proposed Z-N PID+FLC scheme can lead to desirable robust speed tracking performance under load torque disturbances.*

Keywords- Direct Field-Oriented Induction Motor, Proportional Integral Derivative, Fuzzy Logic Controller

I. INTRODUCTION

The Vector control, also called field-oriented control (FOC), is a variable frequency drive (VFD) control method which controls three-phase AC electric motor output by means of three controllable VFD inverter output variables like Voltage magnitude, Voltage angle & Frequency.

FOC is a control technique used in brushless DC and AC induction motor applications that was originally developed for high-performance motor applications which can operate smoothly over the full speed range, can generate full torque at zero speed, and is capable of fast acceleration and deceleration but that is becoming increasingly attractive for lower performance applications as well due to FOC's motor size, cost and power consumption reduction superiority.

Not only is FOC very common in induction motor control applications due to its traditional superiority in high-performance applications, but the expectation is that it will eventually nearly universally displace single-variable scalar volts-per-Hertz (V/Hz) control.

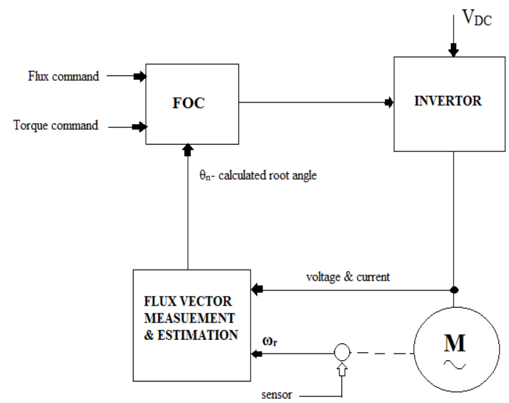

Fig.1 Direct FOC Model

In vector control, an AC induction or synchronous motor is controlled under all operating conditions like a separately excited DC motor. That is, the AC motor behaves like a DC motor in which the field flux linkage and armature flux linkage created by the respective field and armature (or torque component) currents are orthogonally aligned such that, when torque is controlled, the field flux linkage is not affected, hence enabling dynamic torque response.

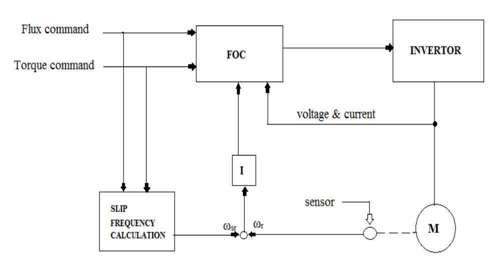

Fig.2 InDirect FOC Model

II. APPLICATION OF VECTOR CONTROL

Stator phase currents are measured, converted to complex space vector in (a,b,c) coordinate system.

Current vector is converted to (α, β) coordinate system. transformed to a coordinate system rotating in rotor reference frame, rotor position being derived by integrating the speed by means of speed measurement sensor. Rotor flux linkage vector is estimated by multiplying the stator current vector with magnetizing inductance L_m and low-pass filtering the result with the rotor no-load time constant L_r/R_r, namely, the rotor inductance to rotor resistance ratio. Current vector is converted to (d,q) coordinate system. d-axis component of the stator current vector is used to control the rotor flux linkage and the imaginary q-axis component is used to control the motor torque. While PI controllers can be used to control these currents, bang-bang type current control provides better dynamic performance. PI controllers provide (d,q) coordinate voltage components. A decoupling term is sometimes added to the controller output to improve control performance to mitigate cross coupling or big and rapid changes in speed, current and flux linkage. PI-controller also sometimes need low-pass filtering at the input or output to prevent the current ripple due to transistor switching from being amplified excessively and destabilizing the control. However, such filtering also limits the dynamic control system performance. High switching frequency (typically more than 10 kHz) is typically required to minimize filtering requirements for high-performance drives such as servo drives. Voltage components are transformed from (d,q) coordinate system to (α, β) coordinate system. Voltage components are transformed from (α, β) coordinate system to (a,b,c) coordinate system or fed in Pulse Width Modulation (PWM) modulator, or both, for signaling to the power inverter section.

III. SIGNIFICANT ASPECTS OF VECTOR CONTROL APPLICATION

- Speed or position measurement or some sort of estimation is needed.
- Torque and flux can be changed reasonably fast, in less than 5-10 milliseconds, by changing the references.
- The step response has some overshoot if PI control is used.
- The switching frequency of the transistors is usually constant and set by the modulator.
- The accuracy of the torque depends on the accuracy of the motor parameters used in the control. Thus large errors due to for example rotor temperature changes often are encountered.
- Reasonable processor performance is required; typically the control algorithm has to be calculated at least every millisecond.

IV. MODELLING OF PID CONTROLLER

A. DESIGN PROCEDURE

The following points are to be taken into account to design the PI controller to get feasible output.

- Obtain an open-loop response and determine what needs to be improved.
- Add a proportional control to improve the rise time.
- Add a derivative control to improve the overshoot.
- Add an integral control to eliminate the steady-state error.
- Adjust each of Kp, Ki, and Kd until you obtain a desired overall response.

The objectives that satisfying the PI-controller design are:

- To fulfill the requirement for the subject BEE4712: Engineering Project.
- To explorer and apply the knowledge gain in lectures into practical applications.
- To control the speed of DC motor with PID controller using MATLAB/SIMULINK application.
- To design the PID controller and tune it using MATLAB/SIMULINK.
- To compare and analyze the result between the simulation result using a DC motor mathematical model in MATLAB/SIMULINK and the experimental result using the actual motor.

B. SIMULINK DIAGRAM FOR PID - CONTROLLER

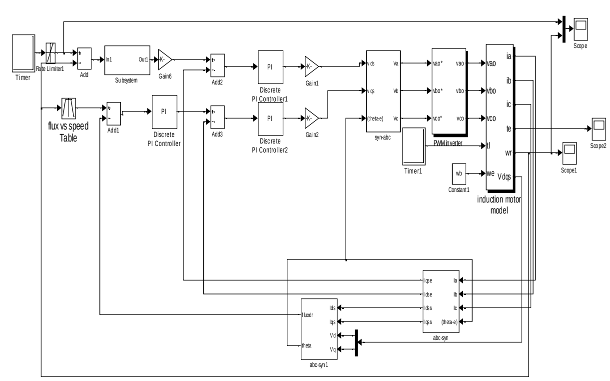

Fig. 3 Modelling of PI- controller

C. DYNAMIC TRANSFORMATION MODEL FOR PID CONTROLLER

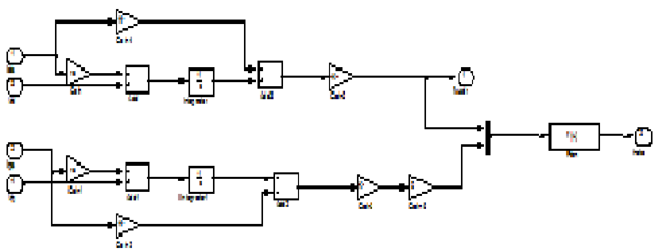

Fig. 4 Dynamic Model of PID- controller

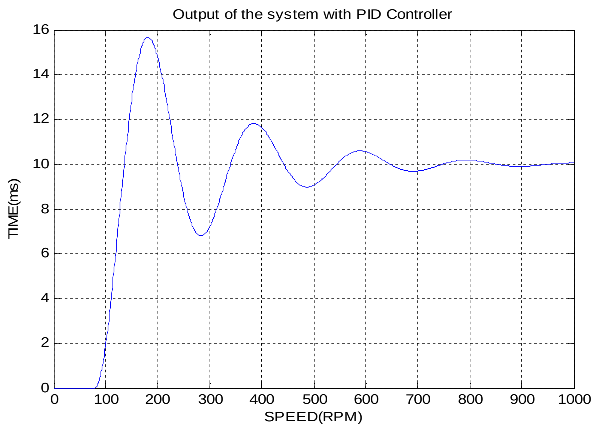

Fig. 5 Output of PID- controller

V. THE PROPOSED HYBRID PID PLUS FUZZY CONTROL

The structure of the proposed controller is shown in Fig. 6.

The steps to acquire the Z-N PID for speed control of the DFOIM in Fig.3 are given as follows. First, we use a fixed step input ω *rm* and a linear proportional speed controller. As a result, we obtain theperiod *Tu* of the critical oscillation at the stability limit of theDFOIM with the critical proportional gain *Ku* . Next, the values of the parameters *K p* ,*TI* , *TD* are given by*KP* = *Ku* /1.7; *TI* = *Tu* / 2; *TD* = *TI* 4 where *KP* is the proportional gain; *TI* is the integral time and *TD* is the derivative time.

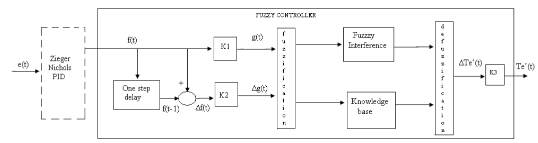

Fig.6 Structure of Hybrid PID + Fuzzy controller

In the fuzzification process, we only employ three input membership functions μ N(x) , μ Z (x) and μ P (x) shown in Fig. 3 to map a crisp input to a fuzzy set with a degree of certainty where $x = g(t)$ or $\Delta g(t)$ with $g(t) = K1\, f(t)$ and $\Delta g(t) = K2 \Delta f(t)$.

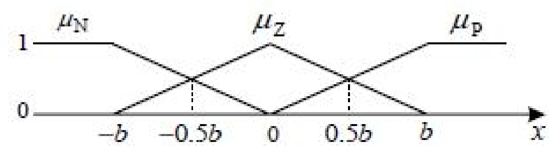

Fig.7 Memebership functions with x= g(t) or Δg(t)

Those three membership functions are chosen because of their simplicity for computation since a large number of membership functions and rules can cause high computational burden for a fuzzy controller. For any $x \in N$ where N denotes the interval $(-\infty,0]$, its corresponding linguistic value is 'N'. Moreover, for any $x \in P$ where P denotes the interval $(0,\infty)$, its corresponding linguistic value is 'P'. For any $x \in Z$ where Z denotes the interval $[-b, b]$, its corresponding linguistic value is 'Z'. The membership functions μ N (x) , μ Z (x) and μ P (x) are given by

$$\mu_N(x) = \begin{cases} 1 & x \le -b \\ \frac{-x}{b} & -b < x \le 0 \\ 0 & \text{otherwise.} \end{cases} \quad \ldots\ldots\ldots \quad (1)$$

$$\mu_Z(x) = \begin{cases} \frac{x+b}{b} & -b < x \le 0 \\ \frac{b-x}{b} & 0 < x \le b \\ 0 & \text{otherwise.} \end{cases} \quad \ldots\ldots\ldots \quad (2)$$

$$\mu_P(x) = \begin{cases} 1 & b \le x \\ \frac{x}{b} & 0 < x \le b \\ 0 & \text{otherwise.} \end{cases} \quad \ldots\ldots\ldots \quad (3)$$

VI. SIMULATION MODEL FOR SPEED CONTROL OF DFOIM USING PID+FUZZY CONTROL

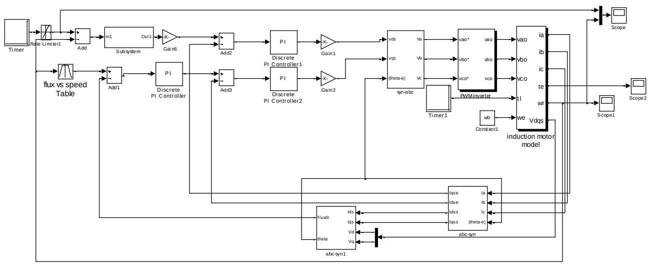

Fig.8 Model of Hybrid PID + Fuzzy controller

Based on the simulation model shown in Fig. 8, the objective of the experiments is to investigate the effectiveness of the proposed speed controller for the Nikki Denso NA21-3F 0.14Hp induction motor. The control system is implemented in real time using the MRC-6810 AD/DA servo control card as the interface between software and hardware.

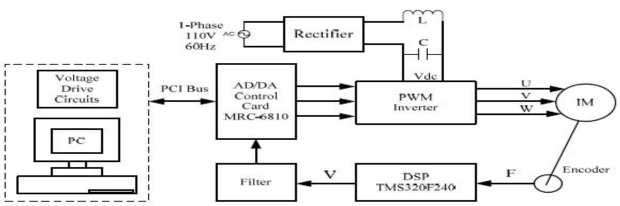

Fig.9 Experimental setup for speed control of DFOIM

In Figs. 10, the performance of the proposed controller compared to other intelligent controllers. The value setting b = 9 and select the best trial-and-error parameter values $K1 = 1.5$, $K2 = 0.05$ and $K3 = 3$ for the FLC under no torque disturbance. In Fig. 10, the command speed is increased from 0 r.p.m. and reaches 1400 r.p.m at 0.40 sec, and then starts decreasing from 1400r.p.m at 0.6 sec. In addition, no torque disturbance is applied to the shaft. It shows that the proposed controller out performs both the NFC and the FLC. The speed tracking response of the FLC yields large fluctuations when the speed command is 1400 r.p.m.. The tracking response of the NFC cannot follow the command speed properly when the speed command is decreased from 1400 to 0 r.p.m..

In Fig. 10, the command speed is the same as that in Fig. 9, and a load torque disturbance of 1.1N-m is applied to the shaft at the 6th second. It is noted that the proposed controller yields much smaller tracking errors than the FLC and the NFC.

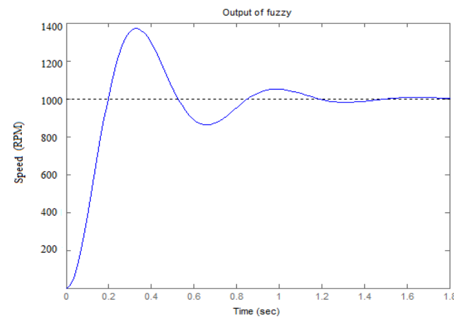

Fig.10 Experimental results of the DFOIM using various speed controllers under load disturbances

VII. CONCLUSION

In this paper, a novel hybrid modified Z-N PID+FLC-based speed control of a DFOIM has been presented. The proposed controller has exhibited the combined advantages of a PID controller and a FLC. Specifically, it can improve the stability, the transient response and load disturbance rejection of speed Control of a DFOIM. The fuzzy logic and only with three membership functions are used for each input and output for low computational burden, which can achieve satisfactory results. Simulation and experiment results have illustrated that the proposed controller scheme has a good and robust tracking performance.

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