International Journal of Electronics Communication and Computer Engineering
Volume 5, Issue (4) July, Technovision-2014, ISSN 2249–071X

Technovision-2014: 1st International Conference at SITS, Narhe, Pune on April 5-6, 2014

An Embedded based Fuzzy System for Induction Motor Variable Frequency Drive

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***Abstract* – Induction motors are the most widely used for appliances, industrial control, and automation; however, many applications need variable speed operations. The rapid development of power electronics controllers in recent years has attracted the attention of researchers for making use of flexible characteristics of an induction motor in variable frequency drives. It presents a compact embedded fuzzy system for three-phase induction motor scalar speed control. The control strategy consists of keeping constant the voltage frequency ratio of the induction motor supply source**

***Keywords* – Fuzzy Control, Induction Motor, Real Time System.**

I. Introduction

Most of all industrial motor applications use AC induction motors. The reasons for this include high robustness, reliability, low price and high efficiency, in order to reduce costs of operation and to maximize long term profit gains for the user. Many industrial processes such as assembly lines must operate at different speeds for different products. Therefore speed control is essential for AC drives. However, induction motors do not inherently have the capability of variable speed operation. Due to this reason, the recent developments in speed control methods of the induction motor have led to their large scale use in almost all electrical drives. . While there are different methods for control, Variable Frequency Drive (VFD) is the most common method of speed control. The VFD control system is considered due to its wide application in industrial fields.

Power electronic control achieves smooth variation of voltage and frequency of the ac output. This when fed to the machine is capable of running at a controlled speed. With the advancement in the semiconductor fabrication technology, both the size and the price of semiconductors have gone down drastically. This means that the motor user can replace an energy inefficient mechanical motor drive and control system with a VFD. The VFD not only controls the motor speed, but can improve the motor's dynamic and Steady state characteristics as well. In addition, the VFD can reduce the system's average energy consumption. The base speed of the induction motor is directly proportional to the supply frequency and the number of poles of the motor. Since the number of poles is fixed by design, the best way to vary the speed of the induction motor is by varying the supply frequency. The torque developed by the induction motor is directly proportional to the ratio of the applied voltage and the frequency of supply. The fuzzy based VFD is described in the second section. Different issues & solutions related to proposed method are described in third section. Summary of the technique for induction motor speed control described in the last section.

II. Fuzzy Based V/F Speed Control System

The speed control of induction motor is carried out by maintaining constant the voltage–frequency ratio in order to avoid the air-gap flux variations. If the supply voltage is varied without frequency adjustment, the induction motor can operate in the flux saturation region or with a weakened field. There are different methods for control, Variable Voltage Variable Frequency or V/F is the most common method of speed control in open loop. Scalar control presents a simple structure characterized by low steady-state error. The constant voltage–frequency scalar control system is considered due to its wide application in industrial fields. The block diagram of the proposed fuzzy-control system is shown in Figure 1. The system will be responsible for measuring the TIM shaft angular speed, achieving the fuzzy control algorithm and generating the sinusoidal modulated PWM signal in order to turn on three phase PWM inverter. The motor speed signal of Induction motor is compared with the reference speed provides the inputs of fuzzy logic controller with the speed error and speed error variation. The variable frequency drive controller is a solid state power electronics conversion system consisting of three distinct sub-systems: a rectifier bridge converter, a direct current (DC) link, and an inverter. Three phase input source is a common electrical system that is used in commercial and industrial installations. Rectifier is a device or circuit that converts alternating current (ac) to direct current (dc), which allow current in one direction only. An inverter is simply a direct current (dc) to alternating current (ac) converter. Inverter driven with PWM pulses through gate driver circuit, it uses solid state relay (SSR).Overview of Variable Frequency Drive control platforms is shown in Figure.2

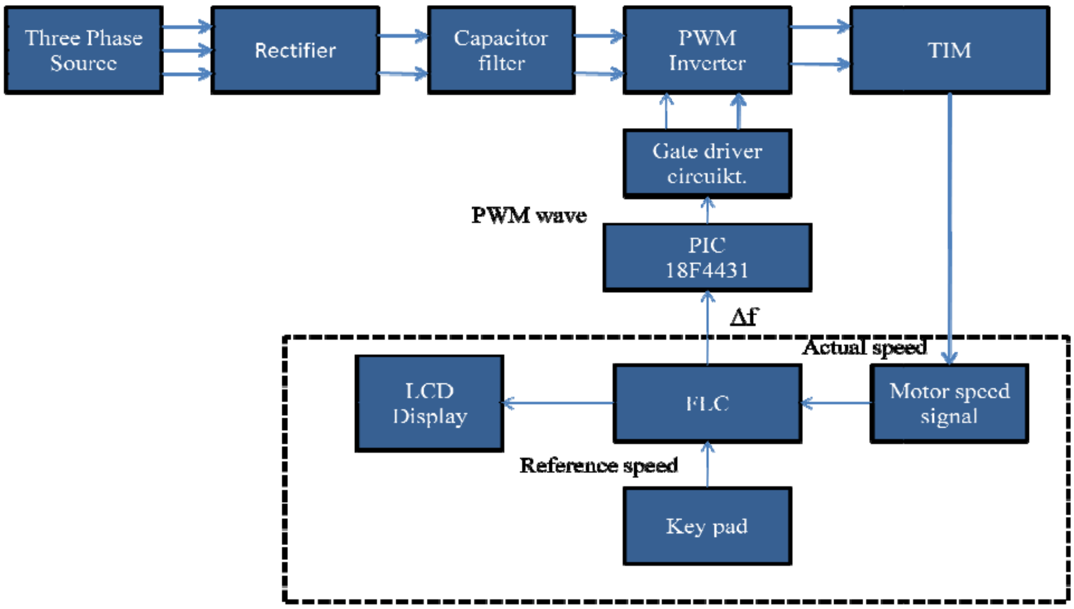

Fig.1. Fuzzy-control system block diagram

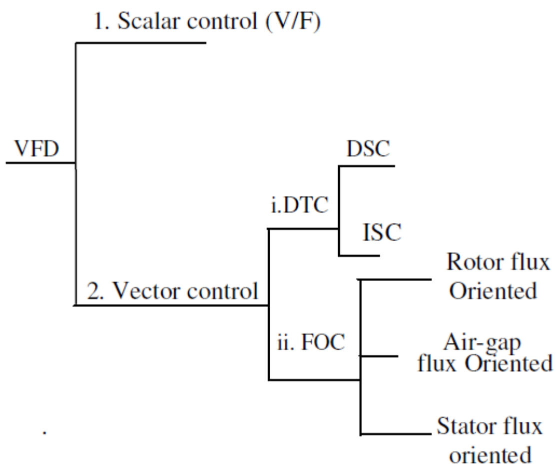

Fig.2. VFD Control platform

DTC – Direct torque control
FOC – Field oriented control
DSC- Direct self control
ISC- Indirect self control

Several studies have been carried out in the field of vector control system [1] due to its better dynamic response However; scalar control presents a simple structure characterized by low steady-state error. Therefore, the constant voltage–frequency (V/f) scalar control system [3] will be considered due to its wide application in industrial fields.

The three phase induction motor is supplied by a PWM inverter with a fundamental frequency and equivalent voltage, such that v/f ratio will kept constant. (FLC) is an expert system implementing a part of a human operators or process engineer's expertise which is not incorporated by conventional differential controllers. It proves to be superior whenever process is unavailable, it gives the better performance compared to conventional controllers. The embedded fuzzy system proposed here will be designed to reduce memory-space requirements and computational effort for real-time applications hardware application, which requires minimal costs, a possible solution is to store a matrix of relation in memory space as a lookup table structure would then be no need to carry out any computation in a fuzzy inference system, since it could be achieved means of simple table indexing. However, this method would demand a large memory space that could increase project costs. On the other hand, in an application where a minimal memory requirement is desired, the whole fuzzy inference process can be calculated online, avoiding storing membership functions in memory. As a result, in many applications, it is recommended that memory requirements and computational effort be traded off, in order to achieve the best structure-satisfying requisites, project costs and real-time performance for a particular application.

III. Methodology

A. Fuzzy Logic Controller

Fuzzy logic controller (FLC) is an expert system implementing a part of a human operators or process engineer's expertise which is not incorporated by control actions employing fuzzy implication and the rules of inference in fuzzy logic. Defuzzification is a scale mapping, which converts the range of values of output variables into corresponding universe of discourse and also yields a non fuzzy control action from an inferred fuzzy control action. This transformation is performed by Membership Functions (MF). In FLC, number of MF and their shapes are initially determined by user.

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Volume 5, Issue (4) July, Technovision-2014, ISSN 2249–071X

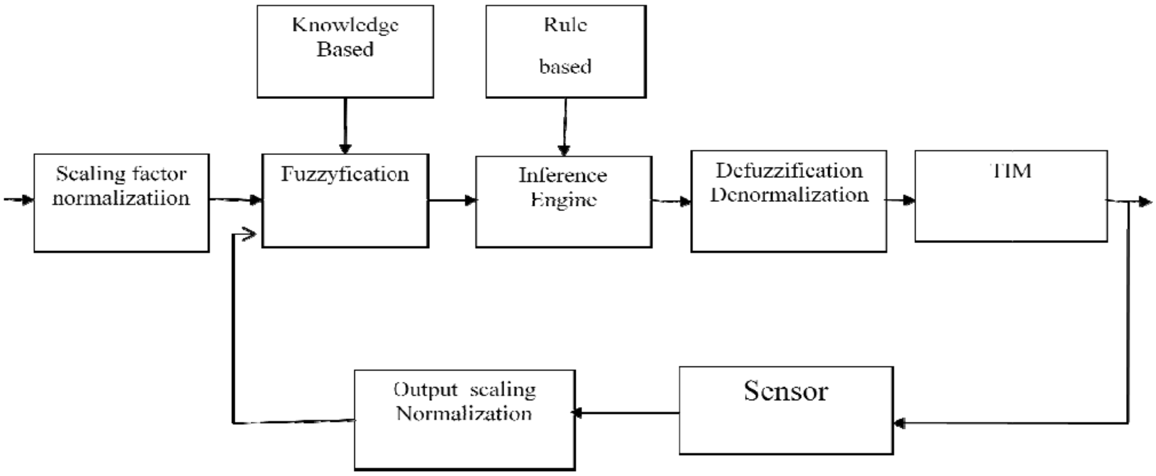

Fig.3. Fuzzy Logic Controller

The knowledge base module of fuzzy controller contains knowledge about all input and output fuzzy partitions. It includes the terms set and corresponding membership functions defining the input variables to the fuzzy rule system and the output variables, or, control actions, to the conventional differential-equation based controllers. It proves to be superior whenever a model of the process is unavailable, it gives the better performance compared to conventional controllers. Today, there are number of products in the market which are controlled by fuzzy logic which different types of FLC are used, the block diagram of the fuzzy logic controller is shown in Figure.3. In general this type of FLC contains four main parts, two of which perform transformations; which are:

a) Fuzzyfier
b) Knowledge base
c) Inference engine
d) Defuzzyfier

The steps in designing a simple fuzzy logic control system are as follows,

a) Identify the variables (input, outputs, and states) of the plant.
b) Partition the universe of discourse or the interval spanned by each variables into a number of fuzzy subsets, assigning each a linguistic label (subsets include all the elements in the universe).
c) Assign or determine a membership function for each fuzzy subset.
d) Assign the fuzzy relationships between the inputs or states fuzzy subsets on the one hand and the outputs fuzzy subsets on the other hand, thus forming the rule-base.
e) Choose appropriate scaling factors for the input and output variables in order to normalize the variables to the [0, 1] or the [-1, 1] interval.
f) Fuzzify the inputs to the controller.
g) Use fuzzy approximate reasoning to infer the output contributed from each rule.
h) Aggregate the fuzzy outputs recommended by each rule.
i) Apply defuzzification to form a crisp output.

B. Fuzzy Control System Rule Database

In order to design a simplified embedded fuzzy inference system for the *V/f* induction-motor control, the triangular and symmetrical membership functions shown in Figure.4 used.

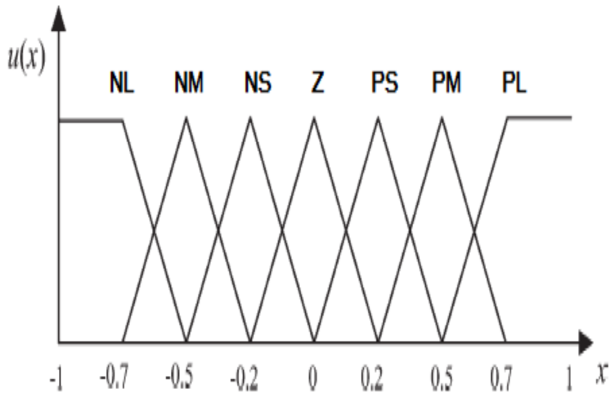

Fig.4. Membership functions of the fuzzy system.

All the linguistic variables of the fuzzy-control system (speed error, speed-error variation, and frequency variation) are scaled into a common discourse universe with values between [−1, 1]. As a consequence, it is possible to map all the variables simultaneously with a unique set of membership functions.

- Input Linguistic variables: Speed error and Speed error variation
- Output Linguistic variables: Frequency variation
- The linguistic terms are described as follows:

NL-“NegativeLarge”;
NM-“Negative Medium” and
NS-“Negative Small”;
ZZ- “Zero”
PS-“PositiveSmall”;
PM-“Positive Medium” and
PL- “Positive Large”

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The discourse universe of the “speed-error” linguistic variable was designed for the [−200, 200] r/min interval. It was therefore normalized to [−1, 1] by dividing the speed error signal before the fuzzification process, as shown in Figure.7. The “speed-error variation” linguistic variable was adjusted to a discourse universe of [−150, 150] r/min, which was divided by 150 to take the signal into the [−1, 1] interval. In a similar way, the “frequency variation” output linguistic variable with a [−1, 1]-Hz interval was multiplied by three to take it to the [−3, 3]-Hz interval.

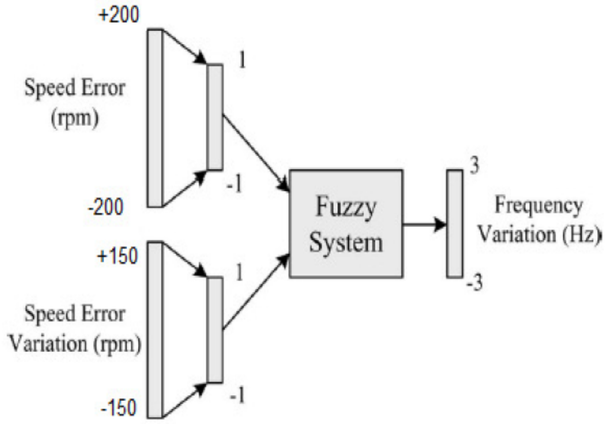

Fig.5. Normalization of the discourse universe

Fuzzy rules can be implemented based on expert knowledge of the control process, which is treated linguistically in an “if–then” structure. As a consequence, it dispenses with the detailed or precise knowledge of the mathematical model that represents the control plant. The rules were based on the studies conducted in [10] whose first two fuzzy rules are represented as follows:

1. If (speed error is **NL**) and
(Speed-error variation is **NL**)
Then (frequency variation is **NL**)
2. If (speed error is **NL**) and
(Speed-error variation is **NM**)
Then (frequency variation is **NL**)

After determining the active regions of all rules activated by input variables ‘ωer’ and ‘dωer’, the aggregation operation carried out. As a result, a union of all individual contributions of each active rule was according to Figure.6.

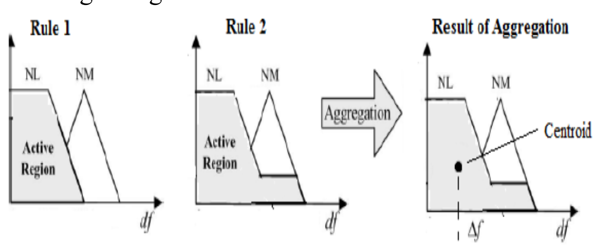

Fig.6. Mamdani fuzzy inference implication method

Mamdani Fuzzy Inference Implication Method

The Mamdani operator, shown in Figure.4 to its computational simplicity. In this generic example, two fuzzy rules activated by the linguistic variable speed error (ωer) and speed-error variation (dω) “Rule 1” the linguistic terms activated by NL and NM, respectively. The Mamdani implication method achieves the minimum between membership values of term in order to obtain the active output region associated with “Rule 1 (NL),” as shown in Figure.

The output value (Δ*f*) represents of IM supply voltage.

C. Sinusoidal PWM Signal Generation

Sinusoidal reference signal is proportional to IM supply voltage, therefore V/F ratio is obtained by controlling reference signals (Δ*f*) amplitude and frequency through Fuzzy logic. A triangular carrier is defined timer, whose counter is increased according to the internal oscillator frequency. This counter (T1CNT) matches the T1PR register value, which defines the carrier frequency. Therefore, while the T1CNT value is less one Compare register (CMPR), the output is activated at a high level.

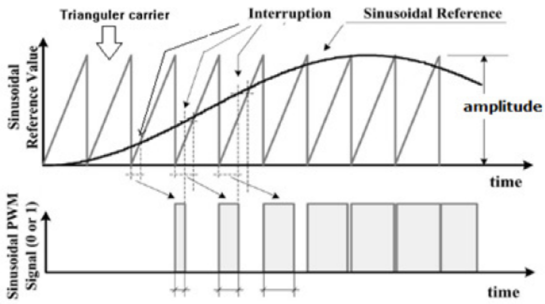

Fig.7.Sinusoidal PWM signal generation

As shown in Figure.7, the algorithm determines the new CMPR value proportional to the sinusoidal reference amplitude for the next period. The signal was stored in the memory space a lookup table structure. As it is proportional to the induction-motor supply voltage, the V/f ratio is obtained by controlling its amplitude and frequency with help of _f (i.e. output value of fuzzy logic)

IV. Conclusion

The proposed fuzzy-control system will be an acceptable alternative method for V/F common control applications A low-cost V/F speed control solution. Additional on-chip resources, like multiple timers and ADC, allow users to easily implement safety and control features The analysis with control platforms such as Direct Torque Control [4], direct self control [5], Indirect Vector Control [1], Stator Flux Control [6] and Scalar control [3] clears that, the proposed embedded fuzzy system for three phase induction motor scalar speed control is having a simplified architecture which reduces memory-space requirements.

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