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FPGA and Fuzzy based Speed Control Technique for Three Phase Induction Motor

Dr. R. Ilango[1], Prof. V. Ashokkumar[2], Prof. G. Gabriel Santhosh Kumar[3]
[1]Professor, Department of EEE, K. Ramakrishnan College of Engineering, Tiruchirappalli, Tamilnadu, India.
[2]Asst. Professor, Department of EEE, K. Ramakrishnan College of Engineering, Tiruchirappalli, Tamilnadu, India.
[3]Asst. Professor, Department of EEE, K. Ramakrishnan College of Engineering, Tiruchirappalli, Tamilnadu, India.

***Abstract*--Induction motors are widely finds in many industries as electrical drives due to its robust construction. Wide ranges of speed control of these motors are achieved in many industrial applications with the help of power electronics based converters. This paper proposes a new Space Vector Pulse Width Modulation (SVPWM) based Voltage Source Inverter (VSI) for speed control of an induction motor using Field Programmable Gate Array (FPGA) with Fuzzy logic technique. In this method the motor speed is changed by controlling the frequency and amplitude of the stator voltage. Here the stator voltage to frequency ratio is kept constant. The 3 phase VSI supplies the variable voltage and frequency to the drives, so as to change the speed of the induction motor. This new speed control method is developed using MATLAB/SIMULINK and hardware model also developed. The simulation and the hardware results prove the performance of the proposed speed control method.**

Keywords-- Fuzzy Controller; FPGA; Induction Motor; Space Vector PWM; Speed Control; Voltage Source Inverter.

I. INTRODUCTION

In recent years the application of the induction motors are rapidly raised due to its superior characteristics. Adjustable speed drives are getting very popular in industries to control the induction motors [1]. The Space Vector Pulse Width Modulation (SVPWM) technique is an advanced method suitable for variable speed drives. It is found in many applications in recent years because of its good performance characteristics [2], [3]. Nowadays, Fuzzy logic control techniques are found in many industrial applications for complex processes and gives better control as compared with conventional control techniques [4]. Recently, Field Programmable Gate Arrays (FPGAs) are given greater attention due to its short design cycle, low cost and high flexibility. It gives better advantages than microprocessors and DSPs [5].

This paper describes the simulation and hardware results of space vector pulse width modulation concept based voltage source inverter (VSI) for controlling the speed of an induction motor using FPGA with Fuzzy logic technique.

II. INDUCTION MOTOR SPEED CONTROL

The speed of the rotating magnetic field developed in induction motor stator is given by:

$$N_s = 120f/p \qquad (1)$$

where ‘f’ is frequency and ‘p’ is number of poles.

The induction motor rotor speed is given by the equation:

$$N_r = N_s(1 - s) \qquad (2)$$

Where ‘s’ is the percentage slip of the induction motor. The induction motor speed can be controlled with help of open loop system or closed loop system [6]. Voltage/frequency control method is the example of commonly used open loop algorithms which gives accurate control with minimal cost. It comes under the category of closed loop method, when implementing sensors and feedback loop. The Variable Voltage Variable Frequency (VVVF) control is one of the closed loop control system which are fed by an inverter [7].

For maximum torque operation the motor flux required is:

$$\varphi = \varphi_m \sin(\omega_1 t) \qquad (3)$$

But, the back emf is:

$$e_1 = N d\varphi/dt = N\omega_1\varphi_m\cos(\omega_1 t) \qquad (4)$$

Representing in RMS values:

$$e_1 = 4.44 N f_1 \varphi_m \qquad (5)$$

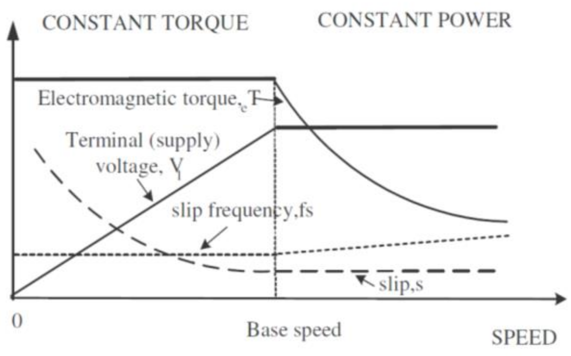

Fig. 1. Operation of VVVF drives under V/ f control method

The fig. 1, illustrates the operating characteristics of a VVVF drive operating under constant V/f control method. The change of voltage ‘V’ with respect to frequency in a V/f control method is shown in fig. 2.

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For all frequencies above the rated frequency the voltage is maintained at rated value and for low frequencies the voltage is kept at a low fixed value.

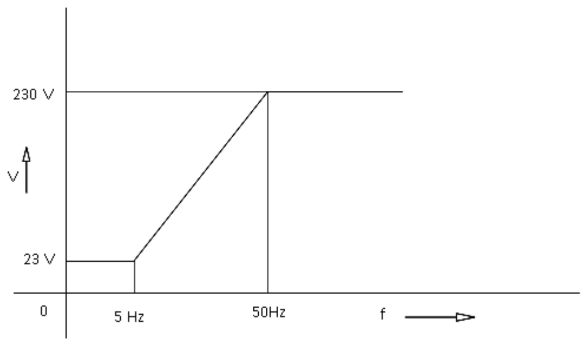

Fig. 2. Variation of voltage with respect to frequency

III. THE PROPOSED SYSTEM DISCRIPTION

The conceptual block diagram of the proposed method is illustrated in fig. 3. In the proposed system the three phase induction motor is controlled by Fuzzy controller using FPGA technique.

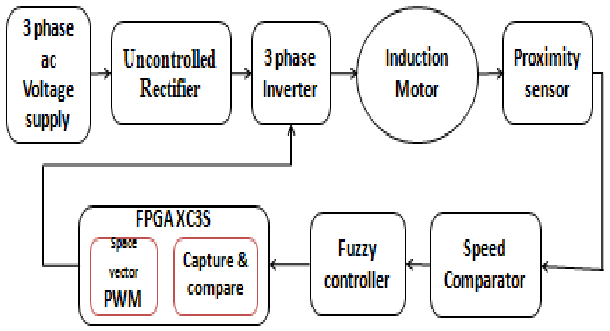

Fig. 3. Proposed speed control block diagram.

A. Space Vector Pulse Width Modulation

There are many Pulse Width Modulation (PWM) methods available to get variable voltage and frequency. Space vector PWM and Carrier-based sinusoidal PWM are the two important PWM methods widely used in voltage source inverters[8]. Space Vector PWM is used recently due to its better performance [9]-[11]. In this paper the space vector PWM method is used to trigger the switches of the power electronics based converter implemented in induction motor speed control. Simulation results are obtained using MATLAB/SIMULINK environment to validate the performance of the proposed speed control system.

B. Voltage Source Inverter

Three phase voltage source PWM inverters are mostly used in industrial drive applications which easy shares large voltages between the series devices. It also gives better power quality output compared with two- level inverter. Nowadays in inverters GTO devices are replaced by IGBTs due to their high voltage and high current rating capabilities with high switching frequency. The SVPWM based three level inverter gives good harmonic quality with larger under-modulation range [12]. In this the motor winding prevents from shoot-through faults and hence no need of additional protective circuit. The diodes available in the voltage source inverter circuit convert utility AC voltage to DC. The converters not used electronic firing like the CSI drive. The parallel capacitors are act as a DC link, which regulate the ripple voltage also store energy needed for the circuit. The PWM pulses are given to the gates of the IGBTs to control the induction motor speed.

C. Field Programmable Gate Array

Field programmable gate arrays are the Integrated Circuit (IC) developed by a customer/designer after manufacturing. The Hardware Description Language (HDL) is normally used to develop the configuration of the FPGA. All the logical function that an ASIC performs can also do by FPGAs. Another advantage of FPGA is that one chip is enough to perform multiple functions. The fig.4, shows the block diagram of XILINX SPARTAN 3E FPGA kit [13].

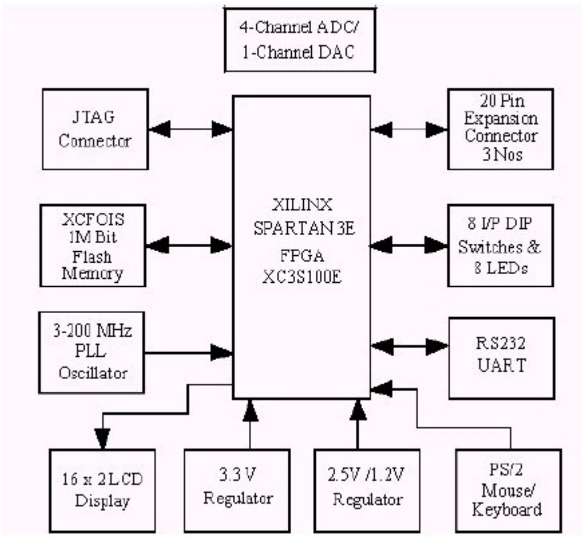

Fig.4. Block diagram of XILINX SPARTAN 3E FPGA kit.

D. Fuzzy Logic Control

The concept of Fuzzy logic is similar to that of the feelings and inference process of a human being. The main difference between the conventional and Fuzzy logic control is in Fuzzy logic a range-to-point / range-to-range control is used where as in conventional control a point-to-point control is used [14]. In Fuzzy logic control technique the most important three steps are

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Fuzzification
Fuzzy Inference Process
Defuzzification

The Fuzzy logic controller block diagram is given in fig. 5. The outputs of a Fuzzy controller are obtained by doing the Fuzzification process of both inputs and outputs using the associated membership functions. A crisp input is converted to the various members of the relevant membership functions based on its value [15].

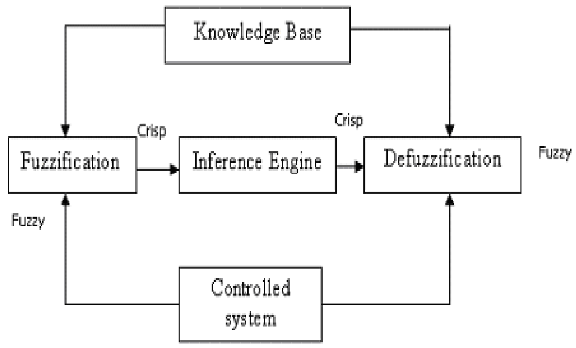

Fig.5. Block diagram of Fuzzy logic controller

E. Fuzzy Control Rules

A Fuzzy IF-THEN rule associates a condition described using linguistic variables and Fuzzy sets to an output or a conclusion. The IF part is mainly used to capture knowledge by using the elastic conditions, and the THEN part can be utilized to give the conclusion or output in linguistic variable form. This IF-THEN rule is widely used by the Fuzzy inference system to compute the degree to which the input data matches the condition of a rule.

F. Fuzzy Mapping Rules

Fuzzy mapping rules provide a functional mapping between the input and the output using linguistic variables. The foundation of a Fuzzy mapping rule is a Fuzzy graph, which describes the relationship between the Fuzzy input and the Fuzzy output. Sometimes, in real applications, it is very hard to derive a certain relationship between the input and the output, or the relationship between those inputs and outputs are very complicated even when that relationship is developed. Fuzzy mapping rules are a good solution for those situations. Fuzzy mapping rules work in a similar way to human intuition or insight, and each Fuzzy mapping rule only approximates a limited number of elements of the function, so the entire function should be approximated by a set of Fuzzy mapping rules.

G. *Mamdani type Minimum Fuzzy Implementation Rule*

Assume that we have two Fuzzy control rules as follows:

R1 : IF x is A1 AND y is B1 ,THEN Z is C1.

R2 : IF x is A2 AND y is B2 ,THEN Z is C2.

In this mode of reasoning, the Fuzzy control rule leads to the control. Consider the whole set of rules with minimum t-norm and Mamdani's minimum fuzzy implication RC; the conclusion can be expressed as a unification of the individual conclusions of Fuzzy control rules.

The fig. 6, shows the Fuzzy reasoning process.

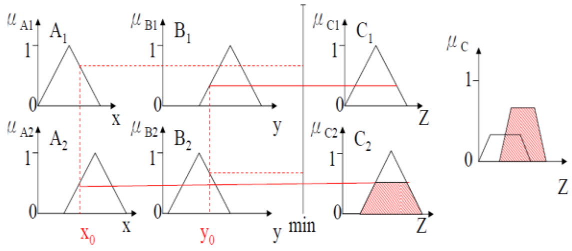

Fig.6. The Fuzzy reasoning process

H. Defuzzification

The conclusion or control output derived from the combination of input, output membership functions and Fuzzy rules is still a vague or Fuzzy element and this process in called Fuzzy inference. To make that conclusion or Fuzzy output available to real applications, a Defuzzification process is needed. It is meant to convert the Fuzzy output back to the crisp or classical output to the control objective. Remember, the Fuzzy conclusion or output is still a linguistic variable, and this linguistic variable needs to be converted to the crisp variable via the Defuzzification process. Three Defuzzification techniques are commonly used, which are: Mean of Maximum method, Center of Gravity method and the Height method.

I. Look up Table

The terminal product of Defuzzification is the lookup table. It needs to be performed for each subset of a membership function, both inputs and outputs.

J. Architectures of Fuzzy Logic Control

Fig. 7, shows block diagram of accurate Fuzzy control, which is a typical Fuzzy closed-loop control system, the inputs are error and error rate, which are combined by block *M* to input to the Fuzzy inference system. The lookup table is derived based on the membership function of inputs, the output and the Fuzzy control rules. A control gain factor *G* is used to tune the output of the lookup table to obtain different output values the interpolation block S is used to smooth the output element of the lookup table. A feedback signal is obtained from the output of the system.

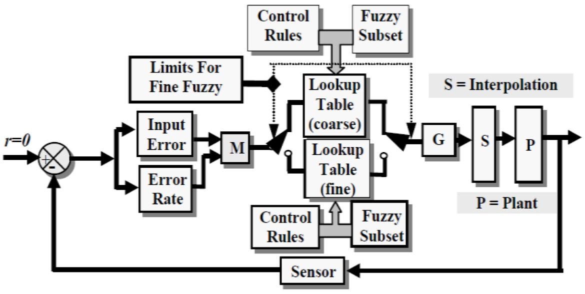

Fig.7. Block diagram of an accurate Fuzzy control

Two lookup tables are developed in this control system, a coarse and a fine table. During the application, the switch between the course and the fine table is under the control of the input error limit. This limit value can be defined by the user based on the real application. Two-set membership functions and control rules are utilized in this system to satisfy the requirement of higher control accuracy. When the system needs quick responses or quick actions, the coarse table is used. When the system needs high control accuracy or small control errors, the fine lookup table is selected. The sacrifice for this method is that more memory is needed to store both coarse and fine tables.

The fig. 8, shows the graph of the input error variable.

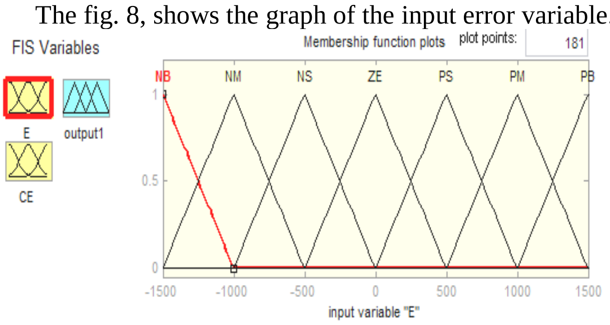

Fig.8. Input error variable

The fig. 9, shows the graph of the change in error variable.

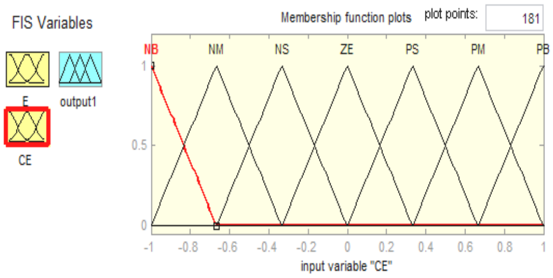

Fig.9. Change in error variable

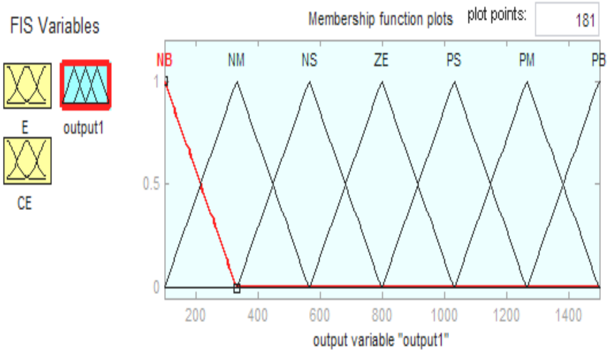

Fig.10. Output variable

The fig.10, illustrates the graph of the output variable.

IV.SIMULATION OF THE PROPOSED METHOD

The proposed speed control method is developed for testing using MATLAB/ SIMULINK environment. A 3 phase A.C. supply is fed to the induction motor through an uncontrolled rectifier and a universal bridge. The actual motor speed and the set speed are compared through the controller of Fuzzy logic circuit. The gate pulses are produced by the Space Vector PWM technique depending upon the error speed. The same is applied to the switches of the converter circuit, which in turn controls the 3 phase induction motor speed.

The following fig. 11 and 12 shows the simulation results waveforms of set speed and actual speed versus time. Here the set speed is given as 1400rpm and the actual speed is gradually increased from 0 rpm to 1400 rpm.

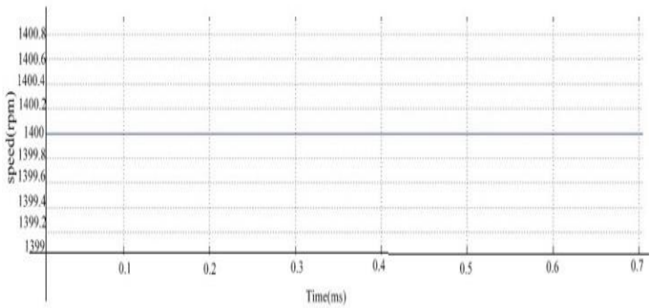

Fig.11. Waveform of set speed in rpm vs. time in seconds

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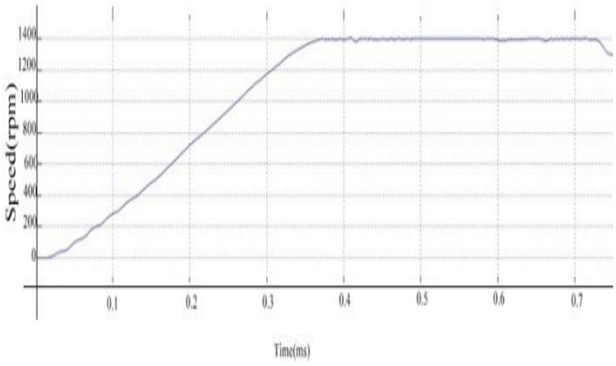

Fig.12. Waveform of actual speed vs. time

V. HARDWARE OF PROPOSED METHOD

The fig. 13, shows the pictorial representation of hardware kit of the proposed control method. In this hardware circuit, 230V line supply is fed to the rectifier circuit through the single phase auto transformer. The rectified dc voltage is filtered through a capacitor and it is fed to the inverter circuit. From the inverter circuit, 3 phase ac voltage is given to the 3 phase induction motor.

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Fig.13. Pictorial representation of the hardware kit

The induction motor speed is sensed by means of MOC7811sensor and it is fed to the FPGA controller kit. The controller compares the actual speed with the set speed and the corresponding gate pulse signals are triggered to the gate of IGBT circuit. Thus the speed of the motor is changed by the inverter circuit corresponding to the difference in the speeds with the help of FPGA controller. The fig.14, shows the hardware results for various speeds.

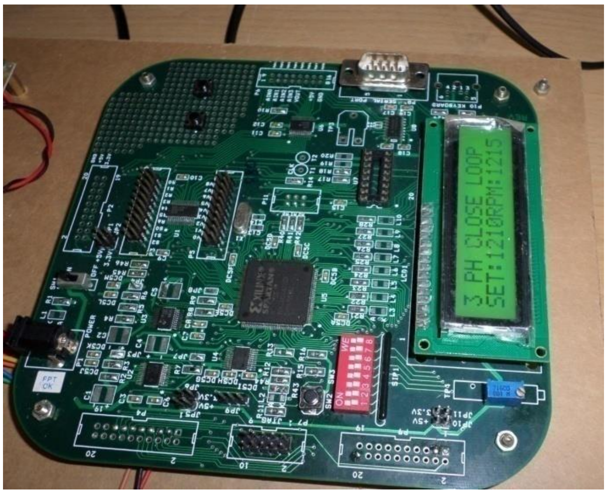

Fig.14. Output of the hardware circuit

VI. CONCLUSION

In this paper FPGA based Fuzzy logic control scheme for controlling the speed of a 3 phase induction motor is presented. This FPGA chips develop triggering signal to drive IGBT based inverter. The structure of FPGA is adapted in parallel, which performs multiple instructions at a time. Furthermore, the Fuzzy controller makes the system less susceptible to noise, temperature and other environmental factors. The simulation and hardware results validate the new speed control scheme.

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