Space Vector Pulse Width Modulation Based Speed Control of Induction Motor using Fuzzy PI Controller

R. Arulmozhiyal, *Member, IEEE,* K. Baskaran, *Member, IEEE*

***Abstract*—This paper presents design and implements a voltage source inverter type space vector pulse width modulation (SVPWM) for control a speed of induction motor. In recent years, the field oriented control of induction motor drive is widely used in high performance drive system.It is due to its unique characteristics like high efficiency, good power factor and extremely rugged .This scheme leads to be able to adjust the speed of the motor by control the frequency and amplitude of the stator voltage, the ratio of stator voltage to frequency should be kept constant.The fuzzy logic controller is also introduced to the system for keeping the motor speed to be constant when the load varies.**

***Index terms* — Fuzzy logic control (FLC), Induction motor. Membership Function, Space Vector Pulse Width Modulation(SVPWM)**

I. Introduction

In recent years, the field oriented control of induction motor drive is widely used in high performance drive system, because of its advantages like high efficiency, very simple, extremely rugged, good power factor and it does not require starting motor [1]. Induction motor are used in many applications such as HVAC (heating, ventilation and air-conditioning), Industrial drives (motion control, robotics), Automotive control (electric vehicles), etc.. In recent years there has been a great demand in industry for adjustable speed drives[2], [3].

The Space Vector Pulse Width Modulation (SVPWM) method is an advanced, computation-intensive PWM method and possibly the best among all the PWM techniques for variable frequency drive application [4] [5]. Because of its superior performance characteristics, it has been finding widespread application in recent years [6].The PWM methods discussed so far have only considered implementation on half bridges operated independently, giving satisfactory PWM performance. With a machine load, the load neutral is normally isolated, which causes interaction among the phases. This interaction was not considered before in the PWM discussion [7].

Recently, Fuzzy logic control has found many applications in the past decade. Fuzzy Logic control (FLC) has proven effective for complex, non-linear and imprecisely defined processes for which standard model based control techniques are impractical or impossible [8]. Fuzzy Logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1[9]. This means that if the a reliable expert knowledge is not available or if the controlled system is too complex to derive the required decision rules, development of a fuzzy logic controller become time consuming and tedious or sometimes impossible. In the case that the expert knowledge is available, fine-tuning of the controller might be time consuming as well [10]. Furthermore, an optimal fuzzy logic controller cannot be achieved by trial-and-error. These drawbacks have limited the application of fuzzy logic control [11]. Some efforts have been made to solve these problems and simplify the task of tuning parameters and developing rules for the controller [12]. These approaches mainly use adaptation or learning techniques drawn from artificial intelligence or neural network theories. Application of fuzzy logic control for the control a speed induction motor using space vector pulse width modulation is quite new [13]. Uncertain systems even in the case where no mathematical model is available for the controlled system. However, there is no systematic method for designing and tuning the fuzzy logic controller.

The aim of this paper is that it shows the dynamics response of speed with design the fuzzy logic controller to control a speed of motor for keeping the motor speed to be constant when the load varies. This paper presents design and implements a voltage source inverter type space vector pulse width modulation (SVPWM) for control a speed of induction motor. This paper also introduces a fuzzy logic controller to the SVPWM in order to keep the speed of the motor to be constant when the load varies.

II. Inverter for AC Drives

A. *Space Vector Pulse Width Modulation*

The SVPWM method considers this interaction of the phase and optimizes the harmonic content of the three phase isolated neutral load as shown in Figure. 1.

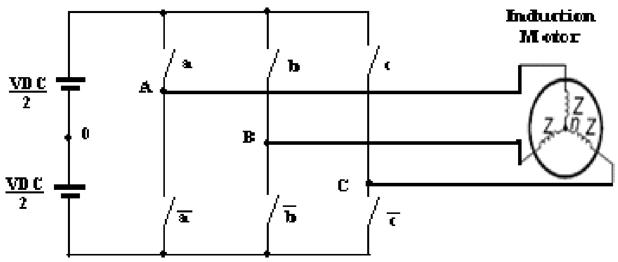

Fig. 1 Voltage source inverter type 3 phase

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The three phase sinusoidal and balance voltages given by the equations as follows:

$$V_{An} = V_m \cos \omega t \qquad (1)$$

$$V_{Bn} = V_m \cos\left(\omega t - \frac{2\pi}{3}\right) \qquad (2)$$

$$V_{Cn} = V_m \cos\left(\omega t + \frac{2\pi}{3}\right) \qquad (3)$$

$$\vec{V} = \frac{2}{3}\left[V_{An} + aV_{Bn} + a^2 V_{Cn}\right] \qquad (4)$$

Are applied to the three phase induction motor, using Equation(4). A three phase bridge inverter, From Figure.1, has 8 permissible switching states. Table I gives summary of the switching states and the corresponding phase-to-neutral voltage of isolated neutral machine.

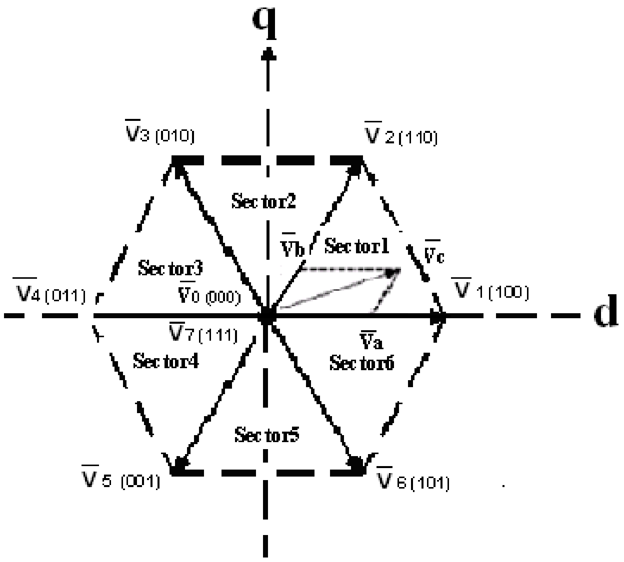


Fig. 2 Space vector of voltage

$$\vec{V}_2 = \frac{2}{3}\left[\frac{V_{DC}}{3} + a\frac{V_{DC}}{3} - a^2\frac{2V_{DC}}{3}\right] = \frac{2}{3}V_{DC} \cdot e^{j\frac{\pi}{3}} \qquad (5)$$

$$V_{no} = \frac{1}{2}\text{median}\,(V_{An}, V_{Bn}, V_{Cn}) \qquad (6)$$

Double edge modulation of reference voltage V_{Ao}, V_{Bo} and V_{Co} are equal as follows:

$$V_{Ao} = V_{An} + V_{no}$$
$$V_{Bo} = V_{Bn} + V_{no} \qquad (7)$$
$$V_{Co} = V_{Cn} + V_{no}$$

TABLE I: SUMMARY OF INVERTER SWITCHING STATES

Name	A	B	C	V_{An}	V_{Bn}	V_{Cn}
V_0	0	0	0	0	0	0
V_1	1	0	0	$2V_{DC}/3$	$-V_{DC}/3$	$-V_{DC}/3$
V_2	1	1	0	$V_{DC}/3$	$V_{DC}/3$	$-2V_{DC}/3$
V_3	0	1	0	$-V_{DC}/3$	$2V_{DC}/3$	$-V_{DC}/3$
V_4	0	1	1	$-2V_{DC}/3$	$V_{DC}/3$	$V_{DC}/3$
V_5	0	0	1	$-V_{DC}/3$	$-V_{DC}/3$	$2V_{DC}/3$
V_6	1	0	1	$V_{DC}/3$	$-2V_{DC}/3$	$V_{DC}/3$
V_7	1	1	1	0	0	0

B. *Simulink Implementation*

To implement the algorithm in Simulink, we shall first assume that the three-phase voltages at the stator terminals must have the following from Equation. (1)-(3), the frequency f and the amplitude V are variables. However, the v/f control algorithm implies that there is a relationship between the amplitude of the voltage and the frequency, i.e. the ratio between the two quantities is constant.

$$K = V/f \qquad [8]$$

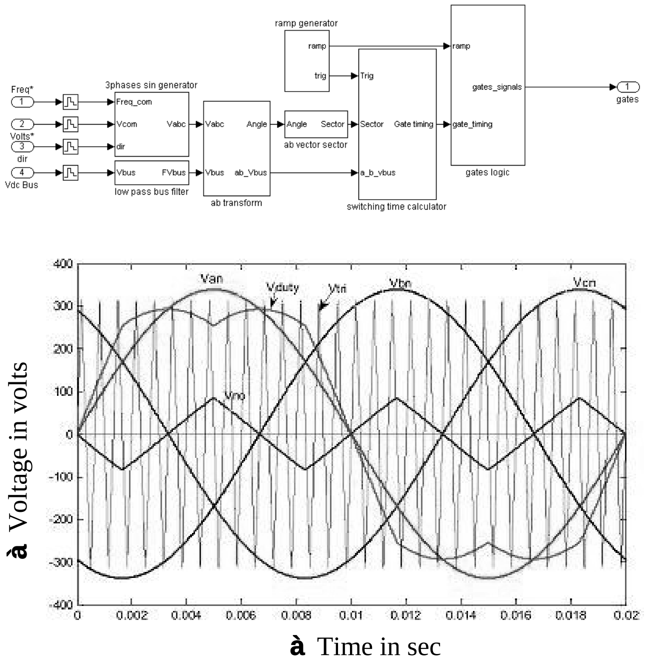


Fig. 3 (a) Simulink implementation of SVPWM, (b) Space Vector Pulse Width Modulation of v/f

III. FUZZY LOGIC CONTROLLER

In drive operation, the speed can be controlled indirectly by controlling the torque which, for the normal operating region, is directly proportional to the voltage to frequency. The speed is controlled by fuzzy logic controller whose output is the reference current of the inner dc current controller. Fuzzy Logic control (FLC) has proven effective for complex, non-linear and imprecisely defined processes for which standard model based control techniques are impractical or impossible. Fuzzy Logic, unlike Boolean or crisp logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1.

In fuzzy logic a particular object has a degree of membership in a given set, which is in the range of 0 to 1. The essence of fuzzy control algorithms is a conditional statement between a fuzzy input variable A and fuzzy output variable B. In general a fuzzy variable is expressed through a fuzzy set, which in turn is defined by a membership function. The torque is controlled by varying the dc current.

The complete block diagram of the fuzzy logic controller is shown in figure 4 and The function of each block and its realization is explained below.

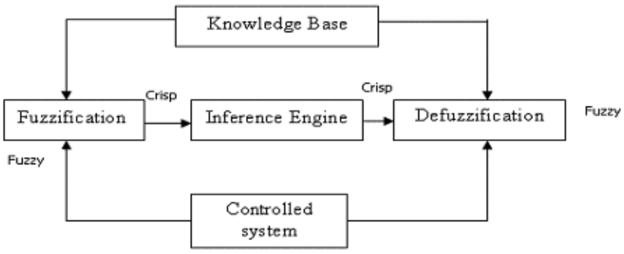


Fig. 4 Block diagram of fuzzy logic controller

A. *Configuration of FLC*

It comprises of four principal components:

- A fuzzification interface
- A knowledge base
- A decision-making logic and
- A defuzzification interface.

(a) Fuzzification

Fuzzification interface involves the following functions.

1. Measures the values of input variable.
2. Performs the function of fuzzification that converts input data into suitable linguistic values

(b) Knowledge base

Knowledge base consist base and a linguistic control rule base.

1. The database provides necessary definitions, which are used to define linguistic control rules.
2. The rule base characterized the control goals and control policy of the domain experts by means of a set of linguistic control rules.

(c) Decision making

The decision-making logic is the kernel of an FLC. It has the capability of simulating human decision-making based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic.

(d) Defuzzication

Defuzzification interface performs the following functions.

1.A scale mapping, which converts the range of values of output variables into corresponding universe of discourse.

2.Defuzzification, which yields a non-fuzzy control action from an inferred fuzzy control action.

B. *Rules creation and inference*

In general, fuzzy systems map input fuzzy sets to output sets. Fuzzy rules are relations between input/output fuzzy sets. The modes of deriving fuzzy rules are based either of the following.

Expert experience and control engineering knowledge.

Operator’s control actions.

Learning from the training examples.

In this thesis the fuzzy rules are derived by learning from the training examples. The general form of the fuzzy control rules in this case is

IF x is Ai AND y is Bi THEN z =fi (x, y)

where x, y and z are linguistic variables representing the process state variables and the control variable respectively. Ai, Bi are the linguistic values of the linguistic variables, fi (x, y) is a function of the process state variables x, y and the resulting fuzzy inference system (FIS) is called a first order sugeno fuzzy model.

C. *Fuzzy inference engine*

The function of the inference engine is to calculate the overall value of the control output variable based on the individual contributions of each rule in the rule base. (i.e.) the defuzzification process. There is no systematic procedure for choosing defuzzification. In first-order sugeno fuzzy model each rule has a crisp output and overall output is obtained as weighted average thus avoiding the time consuming process of defuzzification required in a conventional FLC.

IV. DESIGN OF FUZZY PI CONTROLLER

In drive operation, the speed can be controlled indirectly by controlling the torque which, for the normal operating region, is directly proportional to the voltage to frequency. The speed is controlled by fuzzy logic controller whose output is the reference current of the inner dc current controller. The torque is controlled by varying the dc current. The drive performance of SVPWM is improved by employing two sets of fuzzy logic controllers. From Figure 5 one set of fuzzy logic controller is used in the inner loop for controlling the torque of the motor which is proportional to DC link current Idc, and another set is used in the outer loop for controlling the actual motor speed.

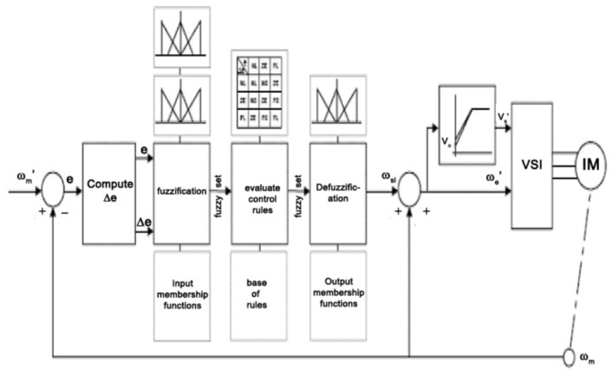


Fig. 5 Design of IM With FLC Architecture

A fuzzy logic controller is proposed to control the speed of the motor to be constant when the load varies. The speed error e and the change of speed error ce are processed through the fuzzylogic controller whose output is the voltage command.current error is usually processed by current regulator to produce a control frequency. This control frequency adjusts the v/f of SVPWM such that the desired speed of the motor can be obtained. In the design of a fuzzy logic controller, seven membership functions were used for both error and change of error. Membership functions were constructed to represent the input and output value.as shown in Figure 7. The fuzzy logic controller consists of three stages: fuzzification, control rules evaluation and defuzzification.

Therefore, the fuzzy logic controllers in the paper will result the higher accuracy in controlling the v/f. A fuzzy logic controller is proposed to control the speed of the motor to be constant when the load varies. The speed error and the change of speed error are processed through the fuzzy logic controller whose output is the voltage command I_{dc} *.

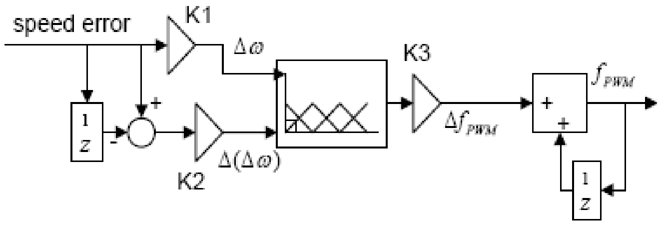
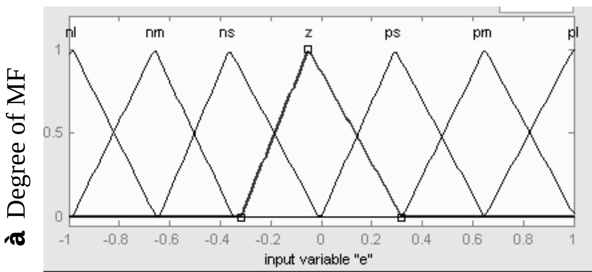


Fig. 6 Block diagram of fuzzy pi controller

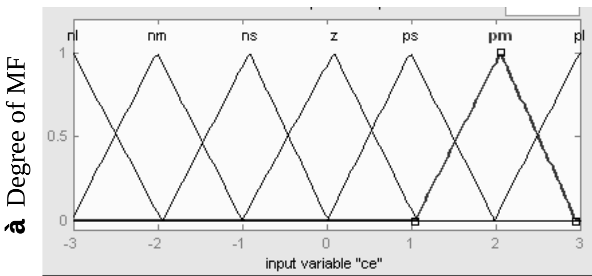
The current error is usually processed by current regulator to produce a control frequency ωe* . This control frequency adjusts the v/f of SVPWM such that the desired speed of the motor can be obtained. Consider the fuzzy speed control system, where the input signal are e(pu) and ce(pu) and the output signal is du, as explained before. Figure 7 shows the fuzzy sets and corresponding triangular MF description of each signal. The fuzzy sets are as follows :Z = Zero, PB = Positive Big, NB = Negative Big, PS =Positive Small, NS = Negative Small, Small, PM = Positive Medium NM = Negative Medium.

The universe of discourse of all the variables, covering the whole region, is expressed in per unit values. All the MFs are asymmetrical because near the origin, the signals require more precision. There are seven MFs for e and ce signal, whereas there are seven MFs for the output. All the MFs are symmetrical for positive and negative values of the variables. Table 2 shows the corresponding rule table for the speed controller. The top row and left column of the matrix indicate the fuzzy sets of the variables e and ce, respectively, and the MFs of the output variable du are shown in the body of the matrix. There may be 7*7 = 49 possible rules in the matrix, where a typical rule reads as:

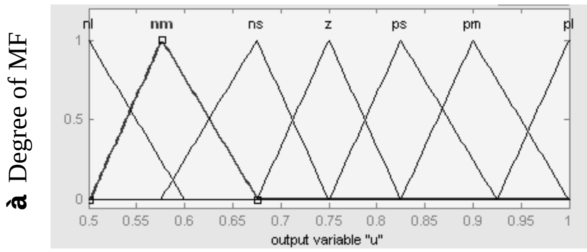
IF ce is PS AND e is NM THEN du is NS.



à Speed Error
(a)



à Change in speed error
(b)



à Voltage
(c)

Fig. 7 Membership functions

(a) MF for speed error (b) MF for change in speed error (c) MF for voltage

TABLE II: RULE BASE OF FUZZY SPEED AND CURRENT CONTROL

ce/e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

V. RESULTS AND DISCUSSIONS

To evaluate the performance of the system, a series of measurements has been accomplished. Figure. 8 as shown performance of the fuzzy logic controller with a fuzzy tuning rule based on Reference speed of 800rpm with no load torque. Figure. 9 as shown performance of the fuzzy logic controller with a fuzzy tuning rule based on Reference speed of 800rpm with load torque. Figure. 10 as shown performance of the fuzzy logic controller with a fuzzy tuning rule based on Reference speed of 1200rpm with no load torque. Figure. 11 as shown performance of the fuzzy logic controller with a fuzzy tuning rule based on Reference speed of 1200rpm with load torque.

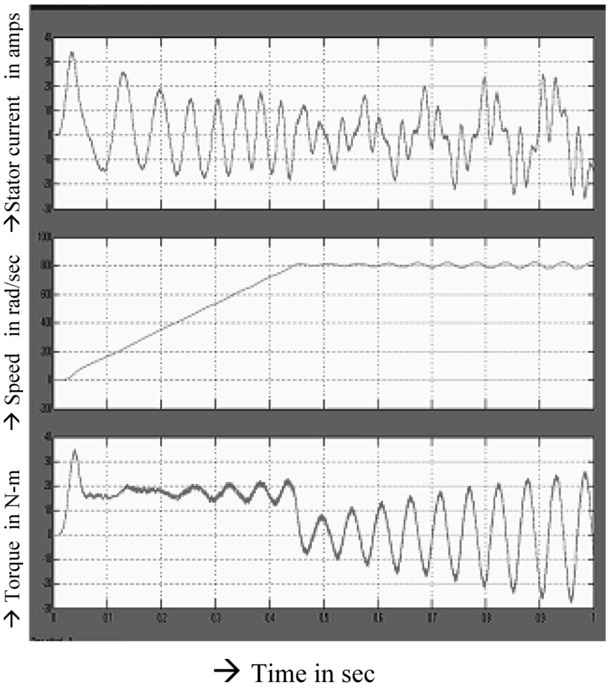


Fig. 8 Reference speed of 800 rpm with no load

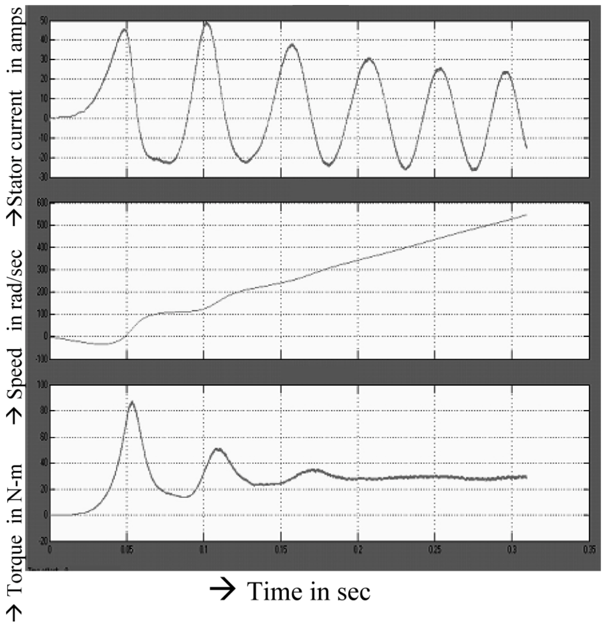


Fig. 9 Reference speed of 800 rpm with load

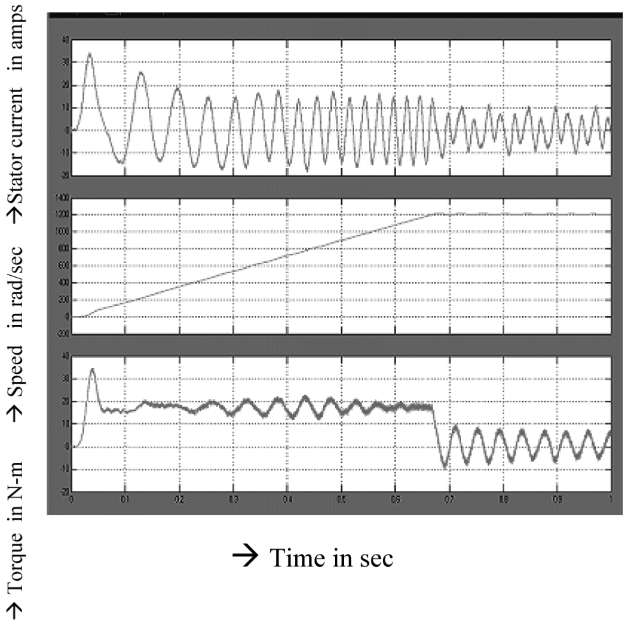


Fig. 10 Reference speed of 1200 rpm with no load

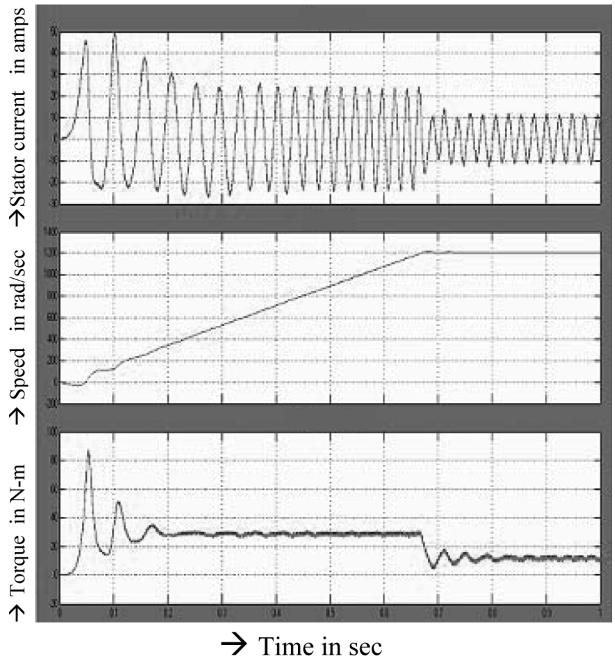


Fig. 11 Reference speed of 1200 rpm with load

From the results tested the performance of controller by a step change of the speed reference at constant load torque as shown in Figure. 11, it's found that the Rise time tr = 0.6s, Settling time ts = 1 sec.

VI. Conclusion

This paper presents simulation results of fuzzy logic control for speed control of induction motor. In fuzzy control it is not necessary to change the control parameters as the reference speed changes, however with the classical PI controller this does not happens. With results obtained from simulation, it is clear that for the same operation condition the induction motor speed control using fuzzy logic technique had better performance than the PI controller, mainly when the motor was working at lower speeds. In addition, the motor speed to be constant when the load varies.

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