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

[1]Yakala Satyanarayana, Dr.A.Srujana

Abstract

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. 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 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. FLC is used to control the pulse width of the PWM converter used to control the speed of the motor.

Index terms — Fuzzy logic control (FLC), Fuzzy PI controller, 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. It is due to its unique characteristics like high efficiency, good power factor and extremely rugged. 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.

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. Because of its Superior performance characteristics, it has been finding widespread application in recent years .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.

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. Fuzzy Logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and1. 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. Furthermore, an optimal fuzzy logic controller cannot be achieved by trial-and-error. These drawbacks have limited the application of fuzzy logic control. Some efforts have been made to solve these problems and simplify the task of tuning parameters and developing rules for the controller.

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.

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 project 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 project presents design and implements a voltage source inverter type space vector pulse width modulation (SVPWM) for control a speed of induction motor. This project 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

For A.C. drive application sinusoidal voltage source are not used. They are replaced by six power IGBT's that act as on/off switches to the rectified D.C. bus voltage. Owing to the inductive nature of the phases, a pseudo-sinusoidal current is created by modulating the duty-cycle of the power switches. Fig.1. shows a three phase bridge inverter induction motor drive.

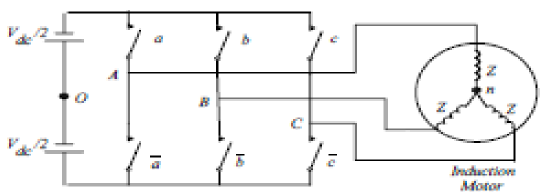


Fig. 1 .Three phase voltage source inverter

$$V_{An} = V_m \cos \omega t$$

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

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

$$\overline{V} = \frac{2}{3}\left[V_{An} + aV_{Bn} + a^2 V_{Cn}\right]$$

Van, VBn, VCn are applied to the three phase induction motor, using Equation $\overline{V}$. 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.

For the three phase two level PWM inverter the switch function is defined as

SWi = 1, the upper switch is on and bottom switch is off.

SWi = 0, the upper switch is off and bottom switch is on.

where *i*= *A,B,C.*

"1" denotes V_{dc} /2 at the inverter output, "0" denotes -V_{dc} /2 at inverter output with respect to neutral point of the d.c. bus. The eight switch states $S_i = (SW_A, SW_B, SW_C)$ where i=0,1,…..7 are shown in Fig. 2. There are eight voltage vectors V_0 - - - - -V_7 corresponding to the switch states S_0 - - - - S_7 respectively. The lengths of vectors V_1 - - - - -V_6 are unity and the length of V_0 and V_7 are zero. These eight vectors form the voltage vector space as depicted in Fig. 3.

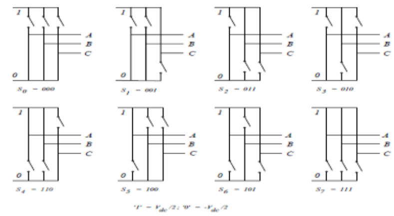


Fig. 2. Eight switching states of VSI.

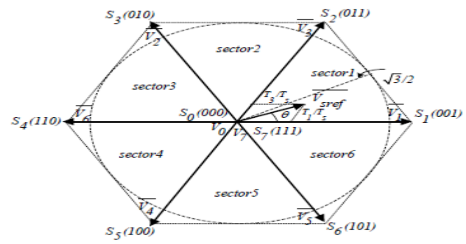


Fig. 3. Voltage space vectors.

The six non-zero voltage space vectors form a hexagonal locus. The voltage vector space is divided into six sectors. It can be seen that when the space vector moves from one corner of the hexagon to another corner, then only the state of one inverter leg has to be changed. The zero space vectors are located at the origin of the reference frame. The reference value of the stator voltage space vector V_{sref} can be located in any of the six sectors. Any desired stator voltage space vector inside the hexagon can be obtained from the weighted combination of the eight switching vectors. The goal of the space vector modulation technique is to reproduce the reference stator voltage space vector (V_{sref}) by using the appropriate switching vectors with minimum harmonic current distortion and the shortest possible cycle time. The eight permissible states are asummarized in Table I.

TABLE I :
SUMMARY OF INVERTER SWITCHING STATES

Voltage vector	SW_A	SW_B	SW_C	V_{An}	V_{Bn}	V_{Cn}
$\overline{V_0}$	0	0	0	0	0	0
$\overline{V_1}$	0	0	1	$-V_{dc}/3$	$-V_{dc}/3$	$2V_{dc}/3$
$\overline{V_2}$	0	1	0	$-V_{dc}/3$	$2V_{dc}/3$	$-V_{dc}/3$
$\overline{V_3}$	0	1	1	$-2V_{dc}/3$	$V_{dc}/3$	$V_{dc}/3$
$\overline{V_4}$	1	0	0	$2V_{dc}/3$	$-V_{dc}/3$	$-V_{dc}/3$
$\overline{V_5}$	1	0	1	$V_{dc}/3$	$-2V_{dc}/3$	$V_{dc}/3$
$\overline{V_6}$	1	1	0	$V_{dc}/3$	$V_{dc}/3$	$-2V_{dc}/3$
$\overline{V_7}$	1	1	1	0	0	0

$$\overline{V_{sref}} = \frac{T_0}{T_s}\overline{V_0} + \frac{T_1}{T_s}\overline{V_1} + \ldots\ldots + \frac{T_7}{T_s}\overline{V_7} \qquad (1)$$

Where T_0 ,T_1 ,......T_7 are the turn on time of the vectors $\overline{V_0}$,$\overline{V_1}$,......$\overline{V_7}$ respectively and T_0 ,T_1 ,......$T_7 \geq 0$, $\sum_{i=0}^{7} T_i = T_s$ where Ts is the sampling time.

In order to reduce the number of switching actions and to make full use of active turn on time for space vectors, the vector V_{sref} is split into the two nearest adjacent voltage vectors and zero vectors V_0 and V_7 in an arbitrary sector. For Sector 1 in one sampling interval, vector V_{sref} can be given as

$$\overline{V_{sref}} = \frac{T_1}{T_s}\overline{V_1} + \frac{T_3}{T_s}\overline{V_3} + \frac{T_7}{T_s}\overline{V_7} + \frac{T_0}{T_s}\overline{V_0} \qquad (2)$$

where $Ts - T_1 - T_3 = T_0 + T_7 \geq 0$, $T_0 \geq 0$ and $T_7 \geq 0$
The length and angle of $Vsref$ are determined by vectors $\overline{V_1}$,$\overline{V_2}$,......$\overline{V_6}$ that are called active vectors and $\overline{V_0}$, $\overline{V_7}$ are called zero vectors. In general

$$\overline{V_{sref}}T_s = \overline{V_i}T_i + \overline{V_{i+1}}T_{i+1} + \overline{V_7}T_7 + \overline{V_0}T_0 \qquad (3)$$

Where T_i ,T_i+1 ,T_7 ,T_0 are respective on duration of the adjacent switching state vectors ($\overline{V_i}$,$\overline{V_i+1}$,$\overline{V_7}$ and $\overline{V_0}$) . The on durations are defined

$$T_i = mT_s Sin(60 - \theta) \qquad (4)$$

$$T_{i+1} = mT_s Sin(\theta) \qquad (5)$$

$$T_7 + T_0 = T_s - T_i - T_{i+1} \qquad (6)$$

Asfollows:
Where m is modulation index defined as:

$$m = \frac{2}{\sqrt{3}} \frac{|V_{sref}|}{V_{dc}} \qquad (7)$$

V_{dc} is d.c. bus voltage and θ is angle between the reference vector $Vsref$ and the closest clockwise state vector as depicted in Fig. 3.

In the six step mode, the switching sequence is $S1$ - S_2 - S_3 - S_4 - S_5 - S_6 - S_1. Furthermore it should be pointed out that the trajectory of voltage vector $Vsref$ should be circular while maintaining sinusoidal output line to line voltage. In the linear modulation range, $\overline{V_{sref}} = \sqrt{3}/2\, V_{dc}$, the trajectory of V_{sref} becomes the inscribed circle of the hexagon as shown in the Fig. 3.

In conventional schemes, the magnitude and the phase angle of the reference voltage vector (i.e. V_{sref} and θ) are calculated at each sampling time and then substituted into (7) and (4), (5) to get the value of on duration. Due to *Sine* Function in (4) and (5) it produces a larger computing delay. Although the use of a lookup table and linear interpolation are used but it increase computation time and interpolation of non-linear function may lead to reduced accuracy and therefore contribute to the deterioration of PWM waveforms.

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. V_{an},V_{Bn},V_{Cn} , 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 [8]

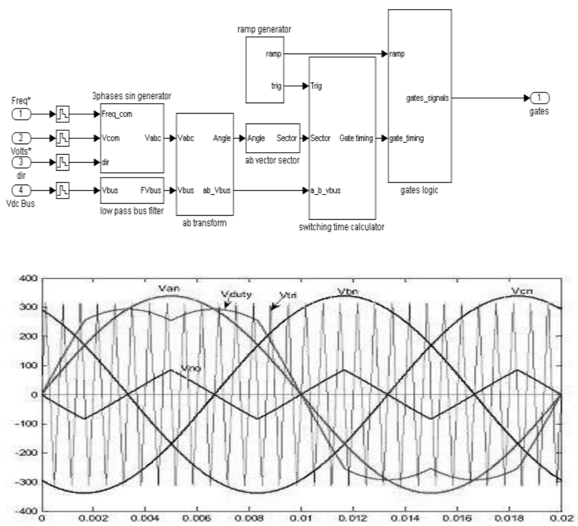


Fig. 4 (a) Simulink implementation of SVPWM, (b) Space Vector Pulse Width Modulation of v/f

III. Fuzzy Logic 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. The complete block diagram of the fuzzy logic controller is shown and The function of each block and its realization is explained below.

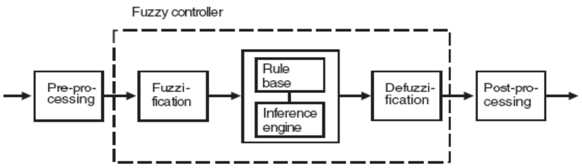


Fig.5.General Fuzzy Block Diagram

A) CONFIGURATION OF FLC:
It comprises of four principal components:
a) A fuzzification interface
b) A knowledge base
c) A decision-making logic and
d) 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 © 2009

b) Knowledge base
Knowledge base consist data 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.

b)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 A_i AND y is B_i THEN z =f_i (x, y)

Where x, y and z are linguistic variables representing the process state variables and the control variable respectively. A_i, B_i are the linguistic values of the linguistic variables, f_i (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 Controllr:

The basic block diagram of a PI type FLC for Induction motor speed control is shown . It is known that a FLC consists of the fuzzification process, the knowledge base and the defuzzification process.

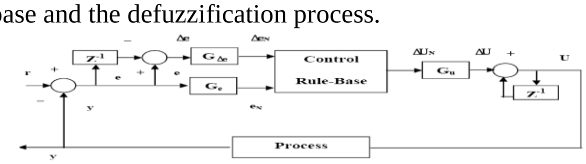


Fig.6 Block diagram of Fuzzy PI Controller

The FLC has two inputs, the error e(k) and change of error Δe(k), which are defined by e(k) = r(k)−y(k), Δe(k) =e(k) − e(k − 1), where r and y denote the applied set point input and plant output, respectively. Indices k and k−1 indicate the present state and the previous state of the system, respectively. The output of the FLC is the incremental change in the control signal Δu(k).The controller has two input variables and one output variable.

The input and output variables of fuzzy PI controller can be defined as:
E(k) = e(k).Ge ….(9)
CE(k) = ce(k).Gce ….(10)
Δi(k) =ΔI(k).$G\Delta i$ ….(11)
where e(k) is the error between reference speed and rotor speed,
ce(k) is the change of error in speed,
I(k) is the output of the fuzzy logic controller,
and Ge, Gce and Gδi are scaling factors.
If e is E and Δe is ΔE, then Δu is Δ

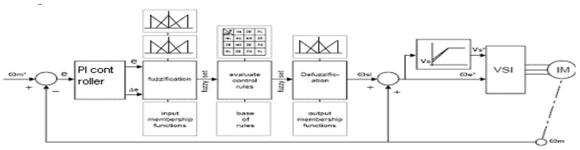
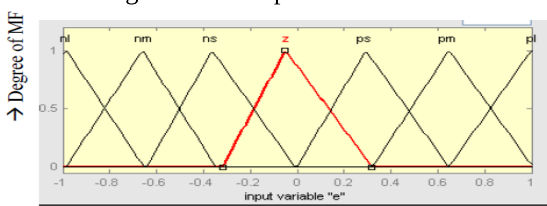
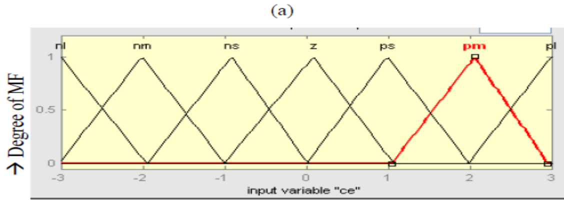


Fig.7 Speed Control of Induction Motor using Fuzzy PI

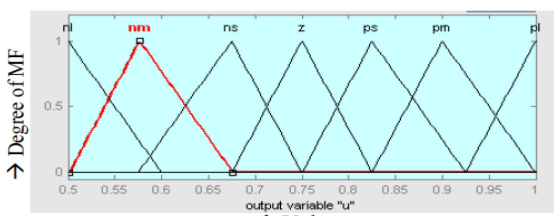
A fuzzy logic controller is proposed to control the speed of the motor to be constant when the load varies. The speed error e and the change of speed error are processed through the fuzzy logic controller whose output is the voltage command. Current error is usually processed by current regulator to produce a control frequency.



→ Speed Error
(a)



→ Change in Speed Error
(b)



→ Voltage
(c)

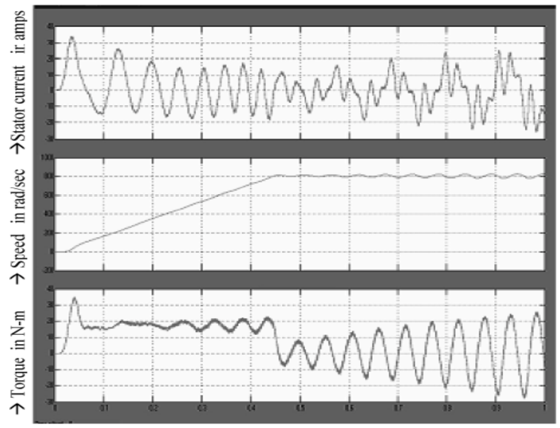
Fig.8 Membership functions
(a) MF for speed error (b) MF for change in speed error (c) MF for voltage

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

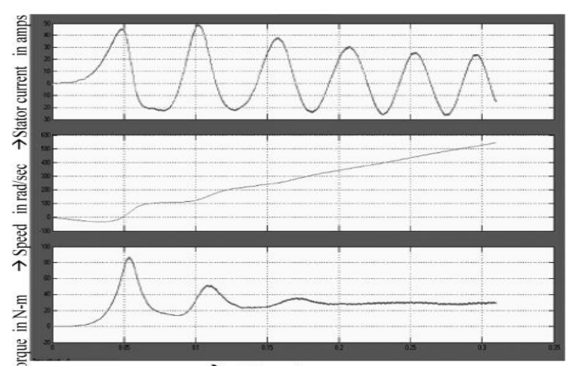
V. Results And Discussions

To evaluate the performance of the system, a series of measurements has been accomplished. Fig . 9 as shown performance of the fuzzy logic controller with a fuzzy tuning rule based on Reference speed of 800 rpm with no load torque. Fig . 10 as shown performance of the fuzzy logic controller with a fuzzy tuning rule based on Reference speed of 800rpm with load torque. Fig . 11 as shown performance of the fuzzy logic controller with a fuzzy tuning rule based on Reference speed of 1200rpm with no load torque. Fig . 12 as shown performance of the fuzzy logic controller with a fuzzy tuning rule based on Reference speed of 1200rpm with load torque.



→ Time in sec

Fig. 9 Reference speed of 800 rpm with no load



→ Time in sec

Fig. 10 Reference speed of 800 rpm with load

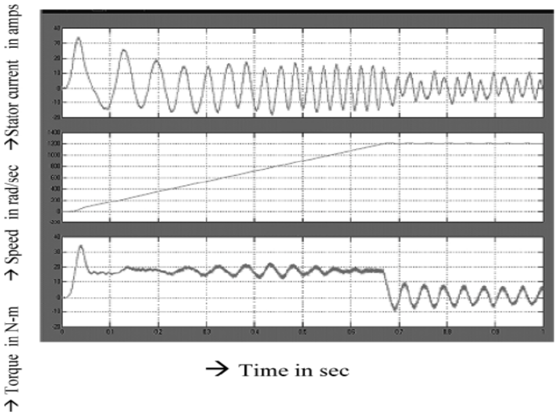


Fig. 11 Reference speed of 1200 rpm with no load

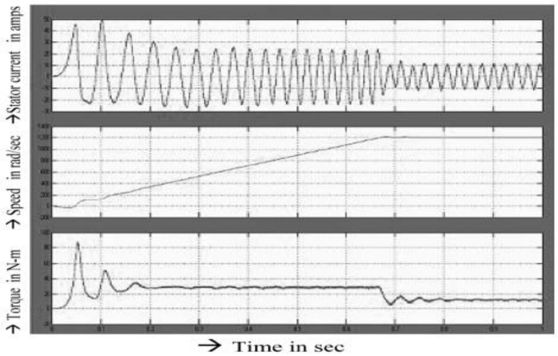


Fig. 12 Reference speed of 1200 rpm with load

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 t_s = 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 PI controller 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.

REFERENCES

[1] W. Leonhard, Control of Electrical Drives, Springer-Verlag Berlin Heidelberg, New York, Tokyo, 1985.

[2] Bimal K.Bose, "Modern Power Electronics and AC Drives", Pearson education .

[3] R.Krishnan, " Electric motor drives", Prentice –Hall India, New Delhi 2005.

[4] A.Iqbal, "Analysis of space vector pulse width modulation for a five phase voltage source inverter"IE (I)journal-EL, Volume 89 Issue 3.September 2008 Pages 8-15.

[5] Mondal, S.K.; Bose, B.K.; Oleschuk, V.; Pinto, J.O.P, "Space vector pulse width modulation of three-level inverter extending operation into overmodulation region", IEEE Transactions on Power Electronics Volume 18, Issue 2, March 2003 Page(s):604 – 611.

[6] Peter Vas, " Artificial –Intelligence based electrical machines and drives", Oxford university 1999.

[7] Andrzej M. Trzynadlowski, "Introduction to Modern Power Electronics", copyright© 1998 by John Wiley & Sons, Inc. All rights reserved.

[8] Chuen Chien Lee, "Fuzzy Logic in Control Systems:Fuzzy Logic controller–Part 1" 1990 IEEE.

[9] Chuen Chien Lee, "Fuzzy Logic in Control Systems : Fuzzy Logic controller –Part 2" 1990 IEEE .

[10] Zdenko Kovaccic and Stjepan Bogdan, "Fuzzy Controller design Theory and Applications", © 2006 by Taylor & Francis Group. International, 2002.

[11] Hassan Baghgar Bostan Abad, Ali Yazdian Varjani, Taheri Asghar "Using Fuzzy Controller in Induction Motor Speed Control with Constant Flux "proceedings of world academy of science, engineering and technology Volume 5 April 2005 ISSN 1307-6884.

[12] Mir.S.A and Malik. E. Elbuluk, (1994), "Fuzzy controller for Inverter fed Induction Machines", IEEE Transactions on Industry Applications, Vol.30. PP. 78-84.

[13] Peter Vas, " Sensorless Vector and Direct Torque control", Oxford university press 1998.

BIOGRAPHY

Yakala Satyanarayana, II-M.Tech
P.E,Department of EEE, SV Engineering College, Suryapet.

Dr.A.Srujana has obtained her B. Tech degree from KITS, Warangal, in 1998 and M. Tech degree From J.N.T.U ,Hyderabad, India, in 2002.She Has obtained her Ph.D from J.N.T.U ,Hyderabad in 2011. She has 14 years of teaching experience. Presently he is working as Professor & H.O.D E.E.E at Sri venkateswara engineering college, Suryapet.