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Comparison of PI and Fuzzy Logic Based Vector Control Scheme of Four Switch Three Phase Inverter Fed Three Phase Induction Motor

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Abstract: ***The paper aims is to construct a fuzzy logic based vector control scheme for controlling some of the parameters such as speed, torque, voltage etc. of indirect vector controlled induction motor drive .Four Switch Inverter is recommended so that cost can be reduced. Sequentially a comparison is to be studied between the PI and Fuzzy Logic Controllers based vector control schemes and the parameters are to be compared so that which one is the best can be inferred.***

Keywords: Vector Control, Three Phase Induction Motor, Four Switch Three Phase Inverter, Fuzzy Logic Controller, PI controller

1. Introduction

Induction motor drives with cage type, is most commonly used in industry for constant speed application. These machines are very economical, rugged in construction and reliable and are available in the ranges of fractional horse power (FHP) to multi-megawatt capacity. Low–power FHP machines are available in single-phase, but poly-phase (three-phase) machines are more commonly used. With the recent advancement in power electronics, Induction motor is becoming popular in variable speed applications.

Dynamically accurate speed/torque regulation is a fundamental requirement for almost all high-performance electrical motor drive systems (5). For ac induction motors (IMs), the fundamental breakthrough to achieve accurate torque control was to model the machine in the synchronously rotating reference frame .This allows the torque and the flux producing processes to be separately identified and regulated, using two alternative strategies as discussed below. Direct torque control (DTC) estimates IM torque and flux from the voltage applied to the stator and the measured stator currents. These estimates are then compared against target objectives using hysteresis regulators, with the outputs directly switching the inverter between active and zero states. While DTC is an effective high-performance motor drive control strategy, it is primarily suited for an analog implementation. It also suffers from variable switching frequency and requires an accurate flux/torque estimator. Vector or field orientated control (FOC) identifies a synchronously rotating flux axis for the IM, and independently controls the in-phase "flux producing" and quadrature "torque producing" of its stator current to achieve rapid torque regulation.

This paper proposes an indirect vector control scheme for an induction motor which is fed by a four-switch inverter using fuzzy logic controller. They improve the robustness of the system. The parameters like steady state error, peak overshoot can be reduced. This improves the efficiency of the system. The computation time is reduced and thus a fast response is attained. [4] Detailed analysis on the various performance parameters of the indirect vector controlled induction motor using PI and Fuzzy has been carried out.

2. Vector Control Scheme of Three Phase Induction Motor

1) Induction Machine Modeling

Dynamic model of an Induction motor can be given by the fifth order system. The dynamic equations followed to implement the control are as follows:.The rotor flux position required for co-ordinate transformation can be obtained from,

$$\theta = \int (\omega_r + \omega_{sr})\, dt. \quad (1)$$

Here, ω_r is the rotor speed and ω_{sr} is the slip frequency.
The slip frequency is given by,

$$\omega_{sr} = (L_m R_r i_{sq}) / (\psi_r L_r) \quad (2)$$

$$\psi_r = L_m i_{sd} \quad (3)$$

In a general dq axes reference frame, the dynamic equations of an induction machine are,

$$V_{sd} = R_s i_{sd} - \omega_r \psi_{sq} + \psi_{sd} \quad (4)$$

$$V_{sq} = R_s i_{sq} + \omega_r \psi_{sd} + \psi_{sq} \quad (5)$$

$$V_{rd} = R_r i_{rd} - \omega_{sr} \psi_{rq} + \psi_{rd} \quad (6)$$

$$V_{rq} = R_r i_{rq} + \omega_{sr} \psi_{rd} + \psi_{rq} \quad (7)$$

The fluxes are given by,

$$\Psi_{sd} = L_s i_{sd} + L_m i_{rd} \quad (8)$$

$$\Psi_{rd} = L_r i_{rd} + L_m i_{rd} \quad (9)$$

$$\Psi_{sq} = L_s i_{sq} + L_m i_{rq} \quad (10)$$

$$\Psi_{rq} = L_r i_{rq} + L_m i_{sq} \quad (11)$$

2) Indirect Vector Control Method

For high performance drive the indirect method of vector control is preferred(4). The indirect vector control method is essentially same as the direct vector control except that the rotor angle θ_e is generated in an indirect manner using the measured speed ω_r and the slip speed ω_{sl}. Fig 1 depicts the indirect vector control using FSTPI. The stator phase currents "a,b,c" are transformed to "dq" by Park's transformation. The flux is estimated from the i_{qs} component and the torque from i_{ds} component. The reference values for i_{ds} and i_{qs} are obtained for rated speed, torque and current. These values then are fed to a controller. The outputs from the controller are again transformed to "abc" currents using

Clarke's transformation. and they are compared with the actual phase currents based on which the triggering pulses are generated for FSTPI.

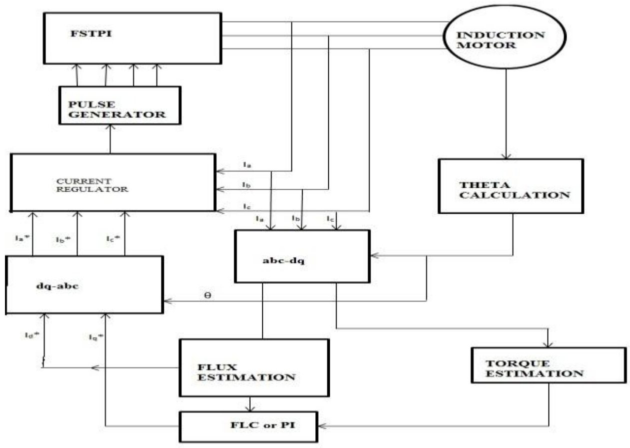

Figure 1: Indirect Vector Control of Induction motor

The electromagnetic torque is given by the formula,

$$T_e=(3P/4)(i_{rq}\psi_{rd}-i_{rd}\psi_{rq}) \quad (12)$$

In these equations,

$\Psi_{sd},\psi_{rd},\psi_{sq},\psi_{rq}$-stator and rotor fluxes with respect to dq axes.

L_m-magnetizing inductance.

L_s,L_r-Total stator and rotor inductances.

3) Four Switch Three Phase Inverter

The invention of high speed power semiconductor devices makes it possible to control the AC drives with six switch three phase (SSTP) inverters. But these inverters have some disadvantages such as losses in the six switches, complexity of the control algorithms and generating six pulse width modulated (PWM) logic signals. In an AC to AC converter with least amount of hardware was proposed for three phase induction motor (IM) drive. A standard six - switch three phase voltage source inverter has six switches in three legs with a pair of complementary power switches per phase. A reduced switch count voltage source inverter i.e. four switch three-phase inverter(FSTPI) Uses only two legs, with four switches. The advantage of this inverter due to the use of 4 switches instead of conventional 6 switches is lesser switching losses, lower electromagnetic interference (EMI), less complexity of control algorithms and reduced interface circuits.

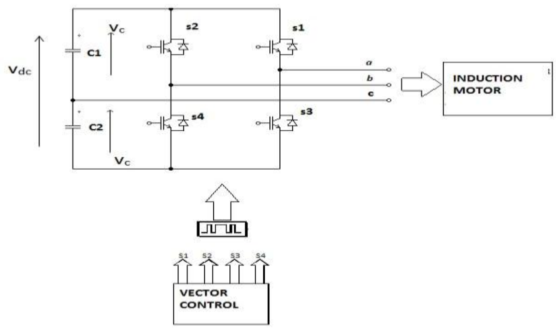

Figure 2: Four Switch Three Phase Inverter Block Diagram

The four power switches are indicated by S1 to S4. The operation can be explained by assigning binary variables to S1 to S4. The binary value "1" corresponds to "ON" state and binary value "0" corresponds to "OFF" state. At any instant the upper switches and lower switches complement each other thus upper switch plus lower switch will be equal to 1. This can be symbolically represented as

$$S1 + S3 = 1 \quad (13)$$

$$S2 + S4 = 1 \quad (14)$$

Invertor output voltages are given by

$$V_{as} = V_c/3\ (4S1 - 2S2 -1) \quad (15)$$

$$V_{bs} = V_c/3\ (-2S1 + 4S2 -1) \quad (16)$$

$$V_{cs} = V_c/3\ (-2S1 - 2S2+2) \quad (17)$$

Where,

V_{as}, V_{bs}, V_{cs} = Invertor output voltages.

V_c = Voltage across the DC link capacitors.

V_{dc}=Voltage across the capacitors C1 and C2.

$$V_{dc}=V_c/2 \quad (18)$$

4) Fuzzy Logic Controller

Fuzzy logic provides a method to formalize reasoning when dealing with vague terms.Traditional computing requires finite precision which is not always possible in real world scenarios. Not every decision is either true or false, or as with Boolean logic either 0 or 1.Fuzzy logic allows for membership functions, or degrees of truthfulness and falsehoods. Or as with Boolean logic, not only 0 and 1 but all the numbers that fall in between.

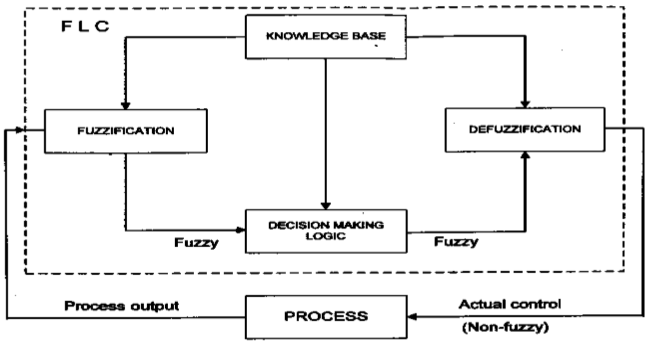

Figure 3: Fuzzy Logic Control System

3. Simulation and Results Discussion

1) Simulation Block Diagram

Vector control of induction motor with conventional controllers and fuzzy controller was implemented in Matlab-Simulink. The results have been obtained for step change in speed and load. The performance of fuzzy controller has been compared with that of the conventional PI controller.

A series of simulation tests were carried out on indirect vector controlled induction motor drive using both PI and Fuzzy based intelligent controller at various time instants. Firstly, the simulation of PI based controller is designed and implemented. A induction motor and Four Switch inverter is common to both the conventional and Fuzzy based controllers. Fig4 shows the overall block diagram of FSTPI fed induction motor.

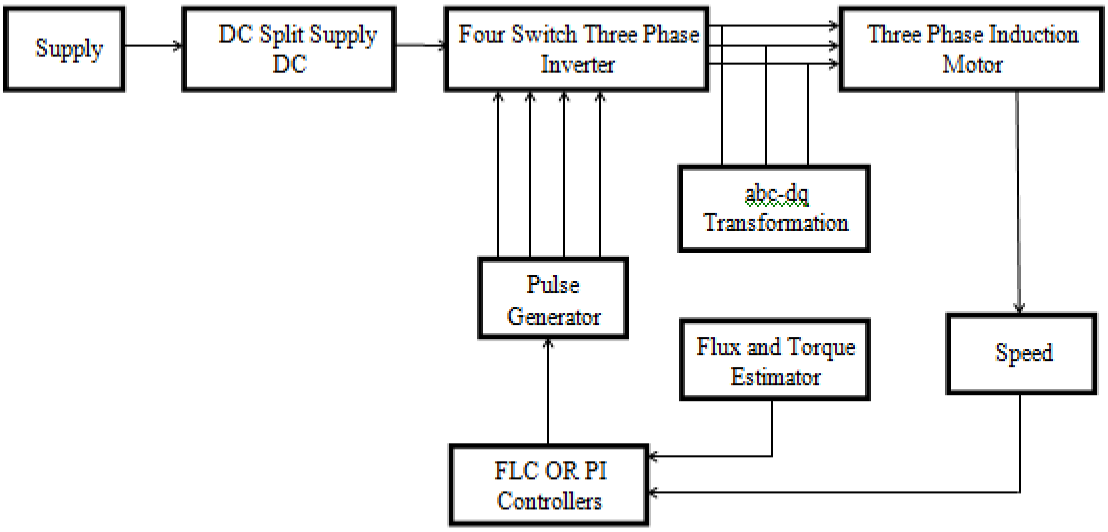

Figure 4: FSTPI Fed Induction Motor Diagram

2) Simulation Parameters & Values

Table 1: Simulation Parameters & Values

Subsystem	*Simulation Parameters*	*Values*
Induction Motor	Power	3 HP
	Voltage	400V AC
	Current	5A
	Speed	1750rpm
	Frequency	50 Hz
	Pole pairs	2
	Inertia	0.089 kg m^2
	Stator resistance	0.435mΩ
	Rotor resistance	0.816mΩ
	Stator inductance	4 mH
	Rotor inductance	2 mH
	Magnetizing inductance	69.3 H

Subsystem	*Simulation Parameters*	*Values*
PI Controller Parameters	Proportional Gain(Kp)	30
	Integral Gain(Ki)	50
FSTPI	Switch	MOSFET
	Capacitor	100µF.
Fuzzy Controller Parameters	Membership function	Triangle
	Defuzzification Method	Centroid
	Inference Method	Mamdani
	No. of Rules	49
	i_d range	(-3,3)
	i_q range	(-2,4)

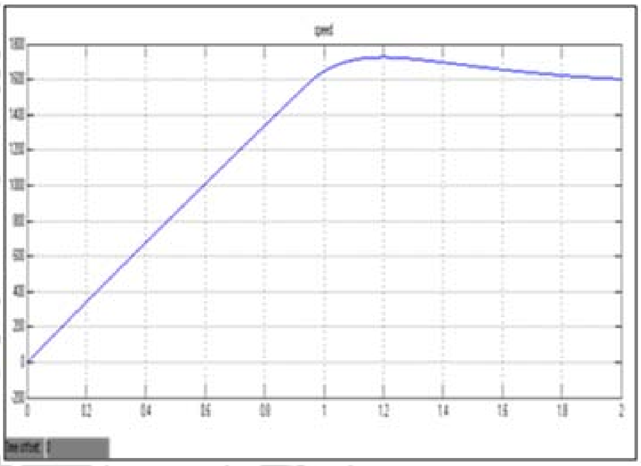

Figure 5: Speed Response using PI controller

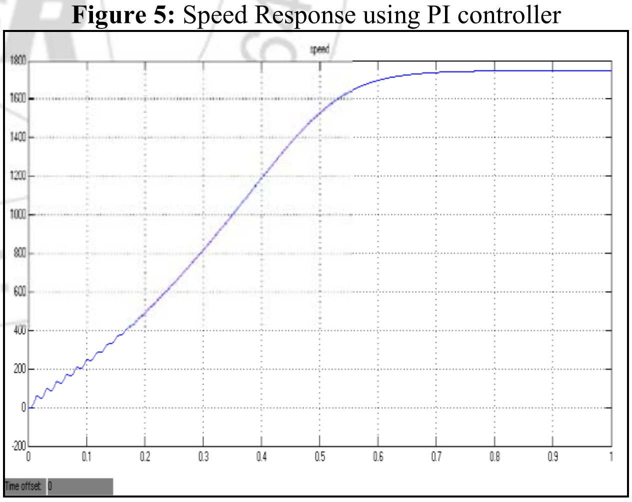

Figure 6: Speed Response using Fuzzy Controller

3) Simulation Results & Discussion

a) Speed Response:

The Speed tracking ability of the conventional and fuzzy controller for given reference speed is shown in fig5 and 6 respectively. The nonlinear I/O capabilities of the fuzzy controller allows for the current to be changed very quickly resulting very accurate speed tracking. The conventional controller reacts slower causing inferior speed tracking.

Inference:
For PI the speed response of the induction motor. The rated speed is 1750 rpm. The speed reaches 1660rpm at 1.8s.Steady state error is 90 rpm/ 5.14%.The speed response using FLC for induction motor.Speed reaches 1700rpm at 0.7s.Steady state error is 2.85%.

b) Torque Response

The torque response of two controller for a step change in load torque are shown in fig7and fig 8.The torque response shows no ripples for FLS and large ripple content for PI controller respectively.

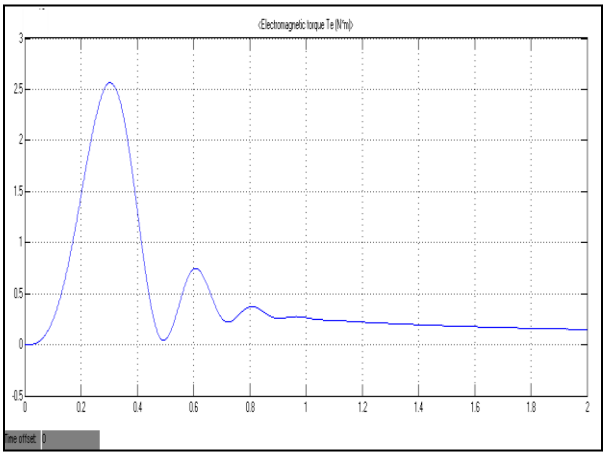

Figure 7: Torque Response Using PI Controller

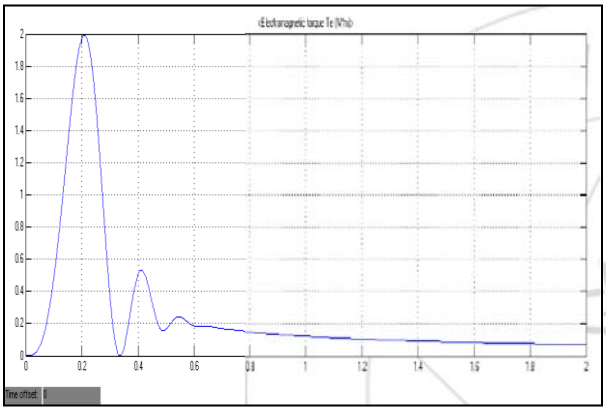

Figure 8: Torque Response using Fuzzy Controller

Inference:
For PI, Rated torque is 3 Nm. Load torque of 2 Nm has been applied. The steady state error is 33.33%.
For FLC, the peak overshoot is recorded as 2 Nm at 0.3s and settles at 1.8 Nm in 0.8s.Steady state error 16.67%.

c) Stator Flux Response
The flux is found to be increased while adopting FLC. The stator flux responses of the induction motor using PI and Fuzzy are shown in figures 9 and 10.

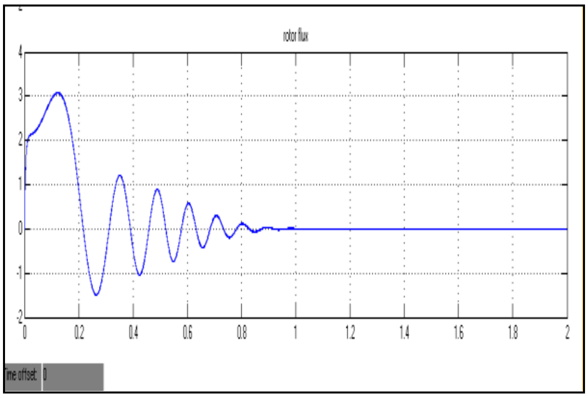

Figure 9: Stator Flux Response using PI Controller

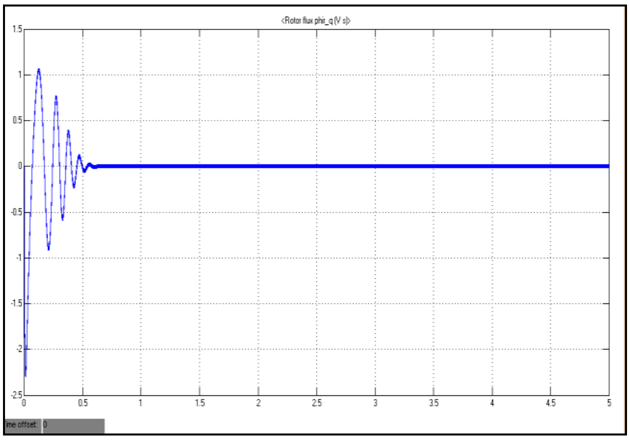

Figure 10: Stator Flux Response using Fuzzy Logic Controller

Inference:
For PI, the rotor flux response. Flux rises to 3Vs at 0.18s and settles at 1 s. at 1.2s.For FLC, the overshoot value is found to be 1 Vs and settles at 0.3Vs at 0.5s.

d) Rotor Flux Response
As similar to stator flux response, rotor flux also enhanced by employing Fuzzy Logic Controller is shown in the figure 11 and 12.

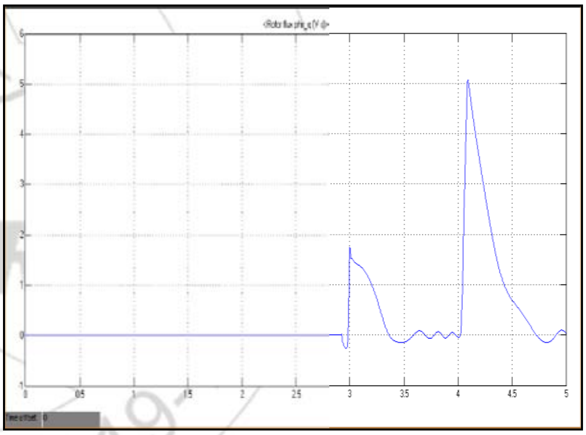

Figure 11: Rotor Flux using PI

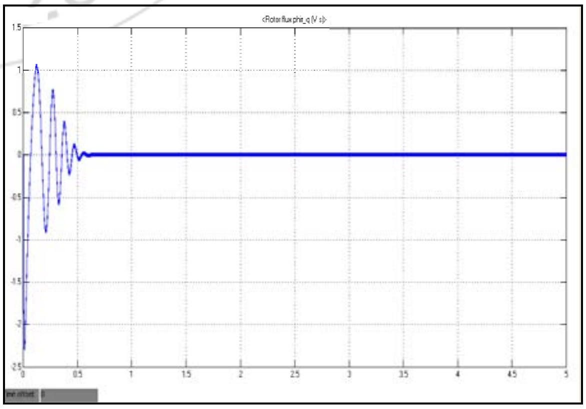

Figure 12: Rotor Flux using FLC

e) Total Harmonic Distortion Using FFT Analysis
The Total Harmonic Distortion is estimated using FFT analysis tool box in the MATLAB.The results exhibit that the distortion had been considerably reduced when using FLC.

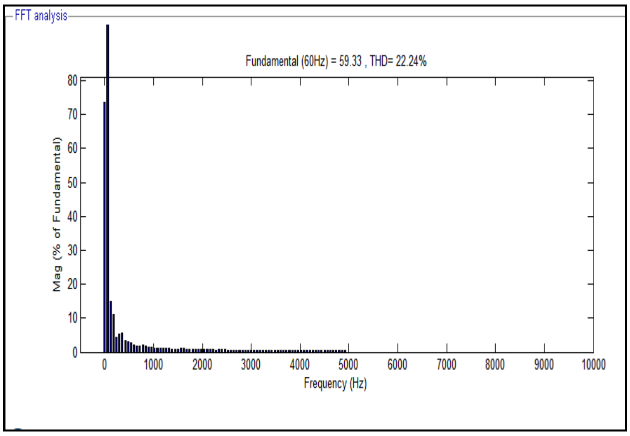

Figure 13: THD using PI Controller

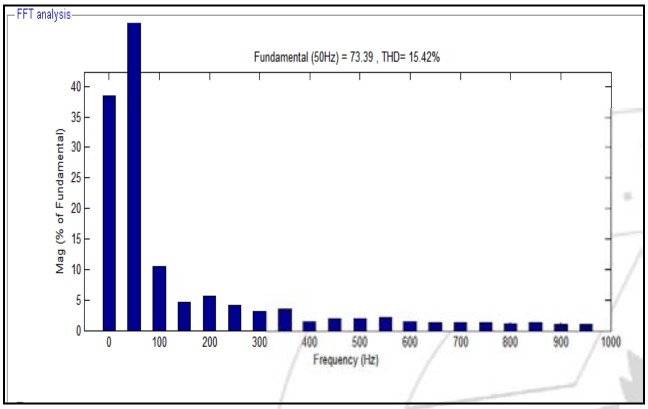

Figure 13: THD using Fuzzy logic Controller

4) Comparison of Simulation Results of PI and Fuzzy Controller adopting VCS

Table 2 gives a comparison of the above obtained simulation results. The induction motor is rated at 3HP, 1750 RPM, 400V, 50Hz squirrel cage motor.

Table 2: Simulation Results

Parameters	PI Controller	Fuzzy Controller
Speed		
Rated Speed-1700rpm		
RPM	1660	1700
Settling Time(s)	1.8	0.7
Steady state Error(%)	5.14	2.85
Torque		
Rated torque 2 N-m		
Peak Overshoot(Nm)	3	2.5
Steady state Error (%)	33.33	16.67
Flux		
1.Peakovershoot(Vs)	3	1
THD		
1.Percentage(%)	22.24	15.42

4. Conclusion

In this paper PI and Fuzzy Based VCS for an Induction Motor is developed and the results are compared and tabulated. The results of Fuzzy seem to be superior in performance compared to Conventional Controller.

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