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Fuzzypi DTC Scheme Based On SVM for Sensorless Induction Motor Drive

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ABSTRACT

This paper describes a mix of direct torque control (DTC) and space vector modulation (SVM) for a customizable speed sensorless induction motor (IM) drive. The motor drive is provided by a two-level SVPWM inverter. The inverter reference voltage is gotten in view of information output criticism linearization control, utilizing the IM display in the stator – axes reference frame with stator current furthermore, transition vectors segments as state factors. Additionally, a powerful full-arrange versatile stator transition observer is intended for a speed sensorless DTC-SVM system and another speed-versatile law is given. By outlining the observer pick up matrix in view of state criticism H_∞ control hypothesis, the strength and robustness of the observer systems is guaranteed. At last, the viability and validity of the proposed control approach is verified by simulation results.

Keywords : direct torque control (DTC), space vector modulation (SVM), induction motor (IM).

I. INTRODUCTION

DIRECT TORQUE CONTROL (DTC) abandonsthe stator current control theory, normal for field oriented control (FOC) and accomplishes bangbang torque and motion control by straightforwardly altering the stator voltage in agreement with the torque and transition errors. Along these lines, it shows a decent following for both electromagnetic torque and stator motion [1]. DTC is described by quick unique reaction, basic straightforwardness, what's more, solid power despite parameter vulnerabilities and perbutations.

One of the inconveniences of ordinary DTC is high torque ripple [2]. A few strategies have been produced to decrease the torque ripple. One of them is obligation proportion control strategy. In obligation proportion control, a chose output voltage vector is connected for a segment of one testing period, and a zero voltage vector is connected for whatever remains of the period. The pulse length of output voltage vector can be dictated by a fuzzy logic controller [3]. In [4], torque-ripple least condition amid one examining period is gotten from immediate torque variety condition. The pulse span of output voltage vector is resolved by the torque-ripple least condition. These upgrades can enormously decrease the torque ripple, however they increment the many-sided quality of DTC calculation. An option technique to lessen the ripples depends on space vector modulation (SVM) strategy[5], [6]. Coordinate torque control in view of space vector modulation (DTC-SVM) save DTC transient benefits, besides, create better quality steady state execution in a wide speed extend. At each cycle period, SVM method is utilized to get the reference voltage space vector to precisely remunerate the motion and torque errors. The torque ripple of DTC-SVM in low speed can be fundamentally progressed. In this paper, SVM-DTC strategy in light of info output linearization control plot for acceptance machine drives is produced. Moreover, a strong full-arrange speed versatile stator transitionspectator is intended for a speed sensorless

DTC-SVM system what's more, a speed-versatile law is given. The spectator pick up matrix, which is gotten by fathoming straight matrix imbalance, can make strides the vigor of the versatile observer pick up in [7]. The steadiness of the speed versatile stator transition spectator is additionally ensured by the pick up matrix in low speed. The proposed control calculations are confirmed by broad extensive simulation results.

II. DTC-SVM BASED ON INPUT-OUTPUT LINEARIZATION

A. Model of Induction Motor

Under supposition of linearity of the magnetic circuit dismissing the iron misfortune, a three-stage IM show in a stationary axes reference with stator currents and motion are expected as state factors, is communicated by

$$\dot{i_D} = -\left(\frac{R_s}{\sigma L_s} + \frac{R_r}{\sigma L_e}\right) i_D - \omega_r i_Q + \frac{R_r \psi_D}{\sigma L_s L_r} + \frac{\omega_r \psi_Q}{\sigma L_s} + \frac{u_D}{\sigma L_s} \quad (1)$$

$$\dot{i_Q} = -\left(\frac{R_a}{\sigma L_s} + \frac{R_r}{\sigma L_e}\right) i_D + \omega_r i_Q + \frac{R_r \psi_Q}{\sigma L_s L_r} - \frac{\omega_r \psi_Q}{\sigma L_s} + \frac{u_D}{\sigma L_s} \quad (2)$$

$$\dot{\psi_D} = u_D - R_s i_D \quad (3)$$

$$\dot{\psi_Q} = u_Q - R_s i_Q \quad (4)$$

where ψ_D, ψ_Q, u_D,u_Q, i_D , i_Q are respectively the**D –Q** axesof the stator flux, stator voltage and stator current vector components,is the rotor electrical angular speed, L_s,L_r ,$L_m$are the stator, rotor, and magnetizing inductances, respectively,$\sigma = 1 - \left(\frac{L_m^2}{L_s L_r}\right)$and $R_s, R_r$are the stator and rotor resistances,respectively.

The electromagnetic torque in the induction motor can beexpressed as

$$T_e = p_n \psi_s \times i_s = p_n(\psi_D i_Q - \psi_Q i_D) \quad (5)$$

where$p_n$is the number of pole pairs.

B. DTC-SVM Based on Input-Output Linearization

The DTC-SVM scheme is developed based on the IM torqueand the square of stator flux modulus as the system outputs;

stator voltage components defined as system control inputs andstator currents as measurable state variables.

Let the system output be

$$y_1 = T_e = p_n \psi_s \times i_s = p_n(\psi_D i_Q - \psi_Q i_D) \quad (6)$$

$$y_2 = |\psi_s|^2 = \psi_{ds}^2 + \psi_{qs}^2 \quad (7)$$

Define the controller objectives and as

$$e_1 = T_e - T_{eref} \quad (8)$$

$$e_2 = \psi_s|^2 - |\psi_{sref}|^2 \quad (9)$$

where , are reference value of electromagnetic torqueand stator flux, respectively.

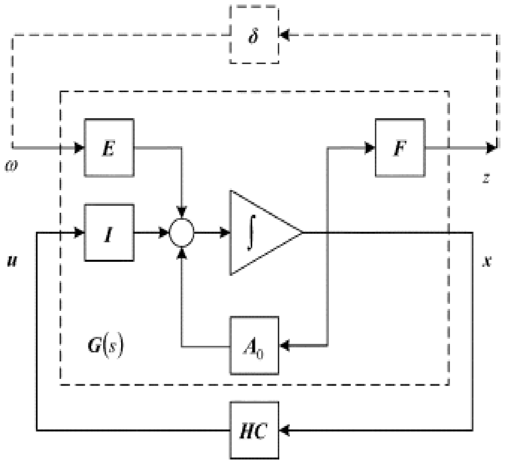

Fig. 1.Standard H_∞ design.

According to (1)–(5), the time derivative of is as (10)

$$\begin{bmatrix} \dot{e_1} \\ \dot{e_2} \end{bmatrix} = \begin{bmatrix} g_1 \\ g_2 \end{bmatrix} + D \begin{bmatrix} u_D^* \\ u_Q^* \end{bmatrix} \quad (10)$$

where

$$g_1 = p_n[c(\psi_D i_Q - \psi_Q i_D) + \omega_m(\; p_n(\psi_D i_D - \psi_Q i_Q) - \frac{\omega_r}{\sigma L_s} \psi_s|^2]$$

$$g_2 = -2R_s(\psi_D i_Q - \psi_Q i_D)$$

$$D = \begin{bmatrix} (i_Q - \frac{\psi_Q}{\sigma L_s}) & -(i_D - \frac{\psi_D}{\sigma L_s}) \\ 2\psi_D & 2\psi_Q \end{bmatrix}$$

$$C = -\left(\frac{R_r \psi_D}{\sigma L_s} + \frac{R_r}{\sigma L_r}\right)$$

According to , the characteristicdeterminant of is as follows:

$$\det(D) = -\frac{4L_m}{\sigma L_r} p_n |\psi_r| . \psi_s \cos(\psi_r, \psi_s) \quad (11)$$

From (11), is D a nonsingular matrix since the inner productof stator flux vector and rotor flux vector can not be physicallyzero.

Based on input-output feedback linearization [8], the followingcontrol inputs are introduced:

$$\begin{bmatrix} u_D^* \\ u_Q^* \end{bmatrix} = \mathrm{inv}(D) \begin{bmatrix} -g_1 + u_x \\ -g_2 + u_y \end{bmatrix} \quad (12)$$

where , are the auxiliary control inputs and are definedbased on the pole placement concept of the linear control systemsso that

$u_x = -c_1 e_1, u_y = -c_2 e_2$ (13)

where$c_1$and $c_2$are positive constants.

III. PEED ADAPTIVE STATOR FLUX OBSERVER

A. Speed Adaptive Stator Flux Observer

Using the IM model of (1)–(4), the speed adaptive stator fluxobserver is introduced:

$$\begin{aligned} \dot{x} &= Ax + BU \\ i_s &= Cx \end{aligned} \quad (14)$$

Where

$\mathbf{x}=(i_D i_Q \psi_D \psi_Q)^T$,$\mathbf{u}=(u_D u_Q)^T$,$\boldsymbol{i}_s = (i_D i_Q)^T$,

$\mathrm{B}=\left[\frac{1}{\sigma L_s}\boldsymbol{I}\ \boldsymbol{I}\right]^{\mathrm{T}}$,C=[I 0], I=$\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}$, J=$\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}$,

$\mathbf{A}=\mathbf{A}_0+\Delta\mathbf{A}_R+\omega_r\mathbf{A}_w$

$$= \begin{bmatrix} -\left(\frac{R_{s0}}{\sigma L_s}+\frac{R_{r0}}{\sigma L_r}\right)\boldsymbol{I} & \frac{R_{r0}}{\sigma L_s L_r}\boldsymbol{I} \\ -R_{s0}\boldsymbol{I} & 0 \end{bmatrix} + \begin{bmatrix} -\left(\frac{\Delta R_s}{\sigma L_s}+\frac{\Delta R_r}{\sigma L_r}\right)\boldsymbol{I} & \frac{\Delta R_r}{\sigma L_s L_r}\boldsymbol{I} \\ -\Delta R_s\boldsymbol{I} & 0 \end{bmatrix} + \omega_r \begin{bmatrix} J & -\frac{1}{\sigma L_s}J \\ 0 & 0 \end{bmatrix}$$

the uncertain parameters in matrix**A**are part in two sections; one relating to apparent or steady operation and the second to obscure conduct. $R_{s0} and\ R_{r0}$what's more, are apparent estimation of stator protection and rotor protection, ΔR_s and ΔR_r are stator protection what's more, rotor protection vulnerabilities, separately.

The state observer, which estimate the state current and the stator motion together, is given by the accompanying condition

$$\frac{d\hat{x}}{dt} = (\boldsymbol{A}_0 + \Delta\boldsymbol{A}_R + \hat{\omega}_R A\omega)+\mathrm{Bu}+\mathbf{H}(\hat{\imath}_s-i_s) \quad (15)$$

where$\hat{\boldsymbol{x}} = (\widehat{\iota_D}\widehat{\iota_Q}\widehat{\psi_D}\widehat{\psi_Q})^{\mathrm{T}}$are evaluated estimations of the state variable and **H** is the spectator pick up matrix.

Assuming state mistake is**e**, i.e**e**=$\hat{\boldsymbol{x}} - \boldsymbol{x}$

$$\frac{d}{dt}(\mathrm{e})=\frac{d}{dt}(\hat{\boldsymbol{x}})-\frac{d}{dt}(\boldsymbol{x})$$

$$=(\mathrm{A}_0+\mathbf{HC}+\Delta\boldsymbol{A}_R + \omega_R\mathbf{A}\omega)\mathrm{e}+\Delta\omega_r\mathbf{A}\omega\hat{\boldsymbol{x}} \quad (16)$$

With a specific end goal to determine the versatile plan, Lyapunov hypothesis is used. Presently, let us characterize the accompanying Lyapunov work:

$$\mathrm{V}=\mathbf{e}^{\mathrm{T}}\mathbf{e}+(\widehat{\omega r} - \omega_r)^2/\boldsymbol{\lambda} \quad (17)$$

The time subordinate of **V** is as per the following:

$$\frac{dV}{dt}=\mathbf{e}[(\mathrm{A}_0+\mathbf{HC}+\Delta\boldsymbol{A}_R + \omega_R\mathbf{A}\omega)^{\mathrm{T}}]+(\mathrm{A}_0+\mathbf{HC}+\Delta\boldsymbol{A}_R + \omega_r\mathbf{A}\omega)\mathbf{e}+\Delta\omega_r(\hat{\boldsymbol{x}}\mathrm{T}\boldsymbol{A}_{\boldsymbol{\omega}}^T\boldsymbol{e} + \mathbf{e}^{\mathrm{T}}\mathrm{A}\omega\hat{\boldsymbol{x}})+\frac{2}{\lambda}(\widehat{\omega r} - \omega_r)\frac{d\widehat{\omega r}}{dt} \quad (18)$$

Let

$$\Delta\,\omega_r(\hat{\boldsymbol{x}}\mathrm{T}\boldsymbol{A}_{\boldsymbol{\omega}}^T\boldsymbol{e} + \mathbf{e}^{\mathrm{T}}\mathrm{A}\omega\hat{\boldsymbol{x}})+\frac{2}{\lambda}(\widehat{\omega r} - \omega_r)\frac{d\widehat{\omega r}}{dt}=0 \quad (19)$$

in the event that we select observer pick up system with the goal that the validity of the disparity

$$\mathbf{e}^{\mathrm{T}}[(\mathrm{A}_0+\mathbf{HC}+\Delta\boldsymbol{A}_R + \omega_R\mathbf{A}\omega)^{\mathrm{T}}]+(\mathrm{A}_0+\mathbf{HC}+\Delta\boldsymbol{A}_R + \omega_r\mathbf{A}\omega)\mathbf{e}< 0 \quad (20)$$

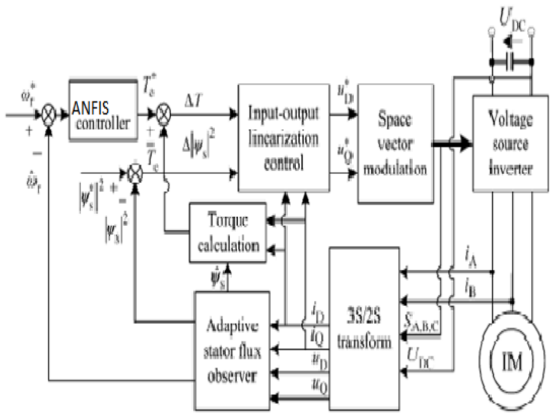

Fig. 2.The block diagram of the existing DTC-SVM system.

ANFIS Controller: An adaptive neuro-fuzzy inference system or adaptive network-based fuzzy inference system (ANFIS) is a kind of artificial neural network that is based on Takagi–Sugeno fuzzy inference system. The technique was developed in the early 1990s. Since it integrates both neural networks and fuzzy logic principles, it has potential to capture the benefits of both in a single framework. Its inference system corresponds to a set of fuzzy IF–THEN rules that have learning capability to approximate nonlinear functions. Hence, ANFIS is considered to be a universal estimator. For using the ANFIS in a more efficient and optimal way, one can use the best parameters obtained by genetic algorithm.

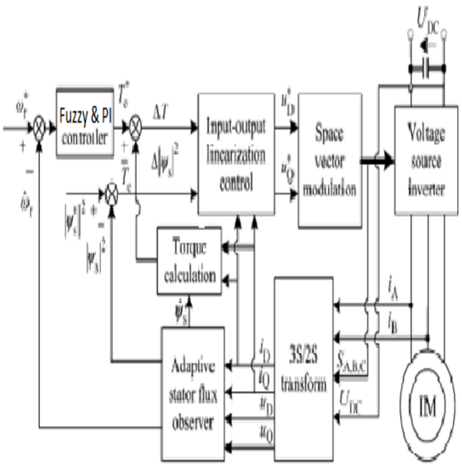

Fig 3 :The block diagram of the Proposed DTC-SVM system.

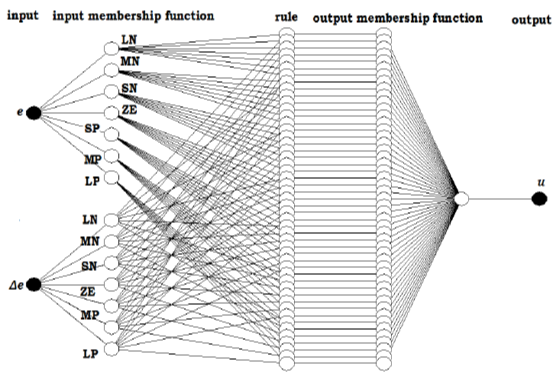

Fig 3: The network of ANFIS controller

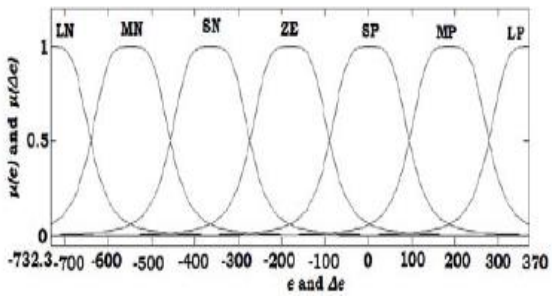

Fig 4: Membership functions for error and change in error.

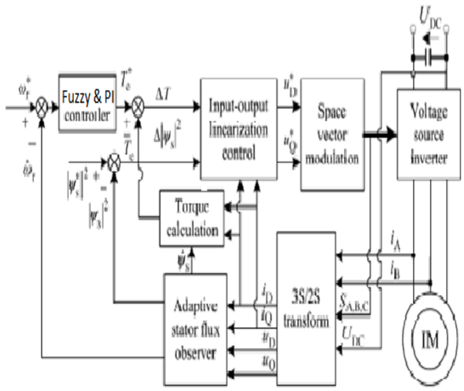

Fig 5 :The block diagram of the Proposed DTC-SVM system.

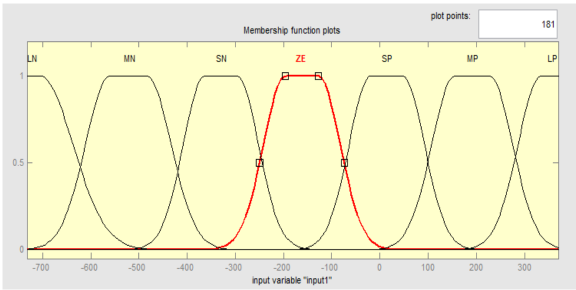

Fig 6:Input 1

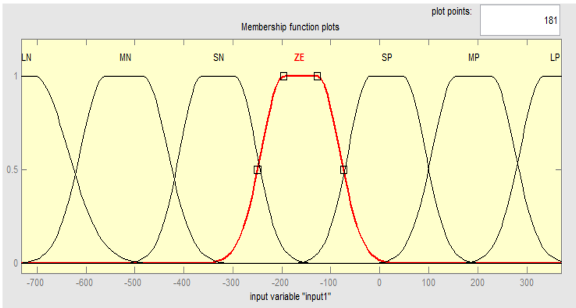

Fig 7 :Input 2

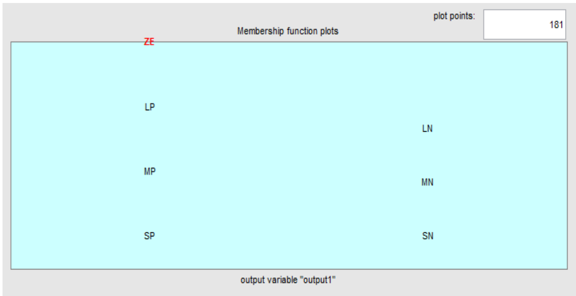

Fig 8:Output

TABLE I

ANFIS RULES

c/ce	LN	MN	S N	Z E	S P	MP	L P
L N	LN	L N	L N	MN	SN	SN	Z E
M N	LN	MN	MN	MN	SN	Z E	S P

S N	LN	MN	S N	S N	ZE	S P	MP
Z E	LN	MN	S N	Z E	S P	MP	L P
S P	MN	S N	Z E	S P	S P	MP	L P
M P	SN	Z E	S P	MP	MP	MP	L P
L P	ZE	S P	S P	MP	L P	L P	L P

can be ensured, the state observer is steady.

The versatile plan for speed estimation is given by

$$\widehat{\omega r} = \left(K_p + \frac{K_i}{P}\right)(\psi_s^T)\boldsymbol{J}(\hat{\iota_s} - i_s) \qquad (21)$$

B. Observer Gain Matrix Computation

Let's introduce a theorem about quadratic solidness of vulnerability system before plan the observer pick up matrix.

Lemma: Uncertainty system

$$\dot{x}(t) = \left(\boldsymbol{A}_0 + \Delta\boldsymbol{A}(T)\right)x(t),\ \ x(0) = x_0 (22)$$

is quadratic stable, if and just if is steady and

$$\|f(s\boldsymbol{I} - \boldsymbol{A}_0)^{-1}\boldsymbol{E}\|_\infty < 1 \qquad (23)$$

where is apparent network, which should be well known, is represents to the vulnerabilities on due to unmodeled conduct or parameter float, and are the vulnerability structure networks of the system, is vulnerability coefficient.

On the off chance that is additionally composed as , so system (16) is quadratic stable, if and just if is steady and

$$\|f(s\boldsymbol{I} - \boldsymbol{A}_0 - \omega r\boldsymbol{A\omega} - HC)^{-1}\boldsymbol{E}\|_\infty < 1 \qquad (24)$$

Assuming ,**K=HC** quadratic steadiness issue of system (16) can be changed to static state criticism control H_∞issue for the system as Fig. 1.

A state-space acknowledgment of Fig. 1 is as (25)

$$\text{G(s)=}\begin{bmatrix} (\boldsymbol{A}_0 + \omega r\boldsymbol{A\omega} & \boldsymbol{E} & \boldsymbol{I} \\ \boldsymbol{F} & \mathbf{0} & \mathbf{0} \\ \boldsymbol{I} & \mathbf{0} & \mathbf{0} \end{bmatrix} (25)$$

As system (25), there will be a state criticism controller , if and just if there are certain clear network and to

make straight matrix imbalance (26) is fulfilled

$$\begin{bmatrix} (\boldsymbol{AX} + \boldsymbol{W} + (\boldsymbol{AX} + \boldsymbol{W})^T & \boldsymbol{E} & (\boldsymbol{FX})^T \\ \boldsymbol{E}^T & -\boldsymbol{I} & \mathbf{0} \\ \boldsymbol{FX} & \mathbf{0} & -\boldsymbol{I} \end{bmatrix} < 0 \quad (26)$$

In the ***X** and W*** event that and is a doable answer for direct systemdisparity (26), at that point **u**=**W*** (***X****)$^{-1}$**x** is a state criticism controller H∞of system (25). In this way, **K=W*** (***X****)$^{-1}$. The spectator pick up matrix can be acquired from **H=KC**$^{-1}$.

TABLE II
PARAMETERS OF IM

Rated power P(kW)	3
Rated voltage Us(V)	3 8 0
Rated current Is(A)	6 . 8
Rated frequency f(Hz)	5 0
Magnetic pole pairs p_n	2
Rated speed n(r/min)	1 4 2 0
Stator inductance Ls(H)	0 . 0 8 6
Rotor inductance Lr(H)	0 . 0 8 6
Mutual inductance Lm(H)	0 . 2 4 3
Stator resistance Rs(Ω)	1 . 6 3 5
Rotor resistance Rr(Ω)	1 . 9
Statorflux linkageψ_s(Wb)	0 . 8

Extension

Fuzzy PI Controller:

Fuzzy logic is a form of many-valued logic in which the truth values of variables may be any real number between 0 and 1. By contrast, in Boolean logic, the truth values of variables may only be 0 or 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions.

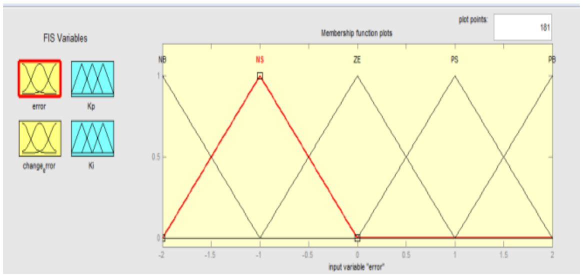

Fig 9: input 1

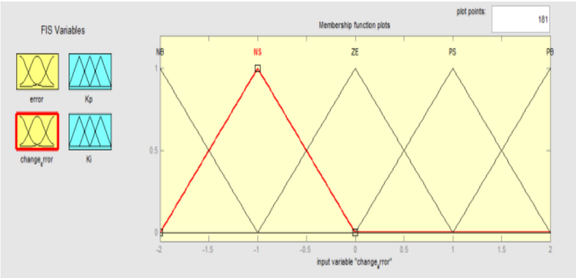

Fig 10: input 2

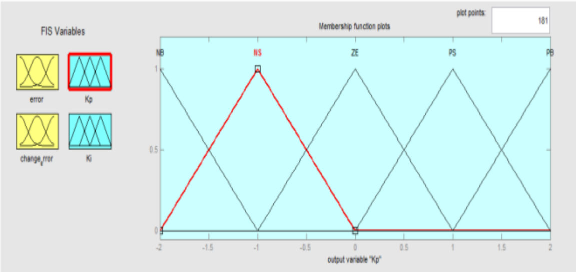

Fig 11: Output Fuzzy Kp

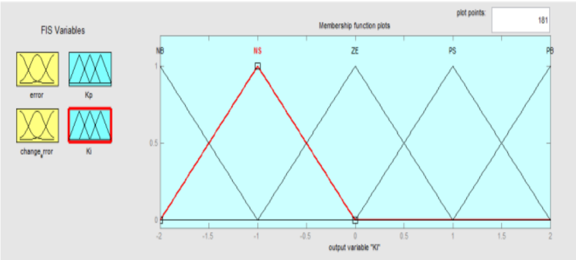

Fig 12:Output Fuzzy Ki

TABLE III

FUZZY PI RULES

c/ce	N B	N S	Z E	P S	P B
N B	Z E	PB,NS	PB,NB	PB,NS	Z E
N S	P S	PB,ZE	PS,NS	ZE,ZE	P S
Z E	P B	PB,PS	ZE,ZE	PB,PS	P B
P S	P S	ZE,ZE	PS,NS	PB,ZE	P S
P B	Z E	PB,NS	PB,NB	PB,NS	Z E

TABLE IV

COMPARISON OF RIPPLE and THD FOR CONTROLLERS

PARAMETER	ANFIS(%)	FUZZYPI(%)
TORQUE	2.4	1.48
CURRENT	4.37	3.13

V. SIMULATION RESULTS

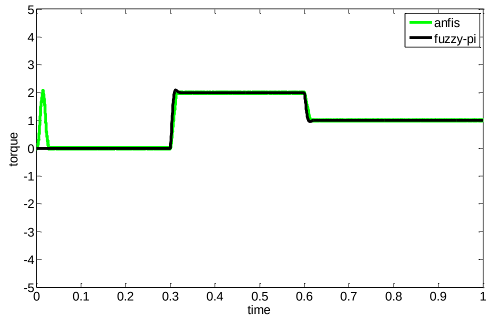

Fig. 13.Torque response curve of Proposed and Extension.

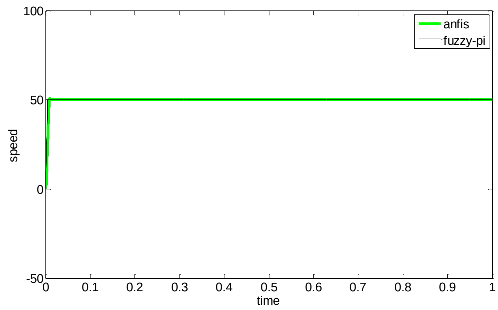

Fig. 14.Speed response curve of Proposed and Extension.

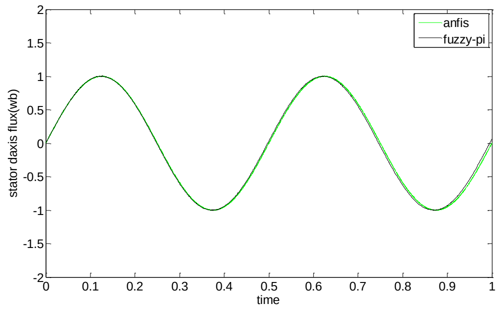

Fig. 15. D-axes stator flux curve.

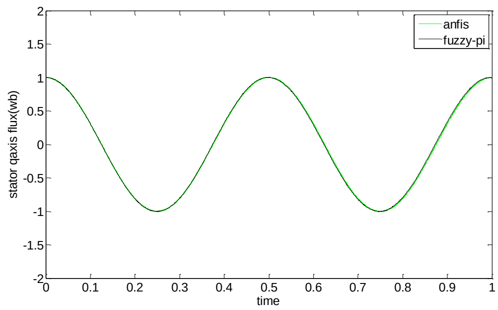

Fig. 16. Q-axes stator flux curve.

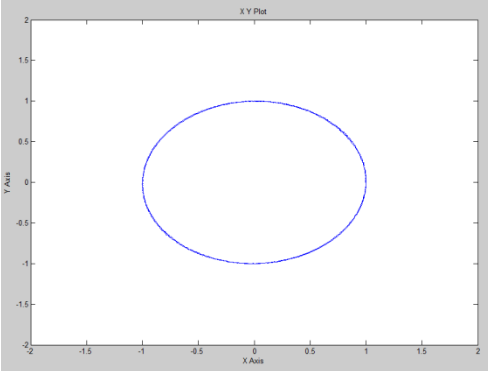

Fig. 17. Stator flux trajectory curve existing

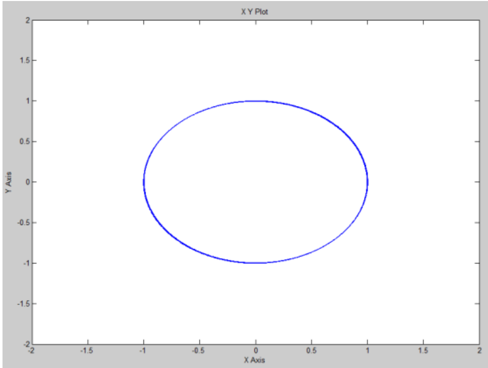

Fig. 18. Stator flux trajectory curve Proposed.

IV. CONCLUSION

A novel DTC-SVM plot has been produced for the IM drive system, which is on the premise of info output linearization control. In this control strategy, a SVPWM inverter is utilized to bolster the engine, the stator voltage vector is gotten to completely adjust the stator motion and torque errors. Besides, a robust full-arrange versatile motion spectator is intended for a speed sensorless DTC-SVM system. The stator motion and speed are evaluated synchronously. By planning the consistent observer pick up network in light of state criticism control hypothesis, the heartiness and soundness of the observer systems is guaranteed. Accordingly, the proposed sensorless drive system is able to do consistently working in low speed, has significantly littler torque ripple and shows great dynamic and enduring state execution.

In future replacing FUZZY-PIcontroller withANFIS-PI will give better performance of the system.

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