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FUZZY CONTROLLER BASED FIELD-ORIENTED CONTROL FOR SIX-PHASE INDUCTION MACHINE

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Abstract:

In the text, the destructive effect of the movement is decreased by use of coordinated field force in the engine of six phases. The high force evaluation of the progress typically uses multi-stage enlistment machines for a multi-day duration. The vector control in the controlling component takes on a simple role to minimise the error when the inverter is working with low waves. The relation between the rotor field and the six-phase inductive engine was arranged with 30° stage relocation between two winding systems in three stages. In the technology suggested, the fluid rational regulator increases the performance compared to the PI regulator. By using matt laboratory/Simulink, you can add the six-phase enlistment engine.

Keywords:

Multiphase induction machine, space vector pulse width modulation (SVPWM), rotor field oriented control (RFOC), load disturbance reduction technique.

I. Introduction:

With increase in the application of electric machines in mining, automotive and industrial sectors, demand towards high powered electric drives is increasing day by day. This higher output power can also be accomplished by employing multi-phase converter fed induction motor drives. high-power electric machine drive frameworks have discovered numerous applications, for example, pumps, fans, blowers, rolling mills, concrete factories, mine lifts, just to give some examples. At present, the best kind of the powerful drive frameworks are cyclo converter - electric machine drives and synchronous machines encouraged by flow source thyristor inverters. Voltage source inverters, despite their good position in line power factor over a cyclo converter just as their bit of leeway of having the option to utilize minimal effort enlistment machines, are as yet restricted to the lower part of the arrangement power run because of the constraints on the entryway turn-off sort semiconductor power device ratings[1,2,3,4].

Space vector beat width adjustment (SVPWM) is prevalent controls conspire for the voltage source inverters. A couple of room vector beat width modulation schemes are found advantageous for multi-phase drives with reduced stator harmonic currents and lower torque pulsation.

Convention SVPWM is similar to that of a three-phase converter, in which reference vector is synthesized by utilizing two adjacent active vectors along with the null vector. In a six-phase VSI, largest space vector lies on the outer most 12- sided polygon [5, 6].

The stator resistance and leakage reactance of the DTIM is less when compared to that of the three-phase machine, which all together diminishes the ability to control the stator harmonic currents. pulse width modulation(PWM) techniques can control harmonic spectrum of the output voltage, thereby improving the output efficiency of an inverter. It can also reduce the torque pulsation. Reducing the number of current sensors in a double three stage engine drive with two three-phase windings with secluded unbiased focuses spatially shifted by 30 electrical degrees (Fig. 1). In particular, this paper shows the RFOC plot, which consists of only two (instead of four) current sensors used in double-stage engine entry drives, with no significant effect on engine power[7, 8, 9].

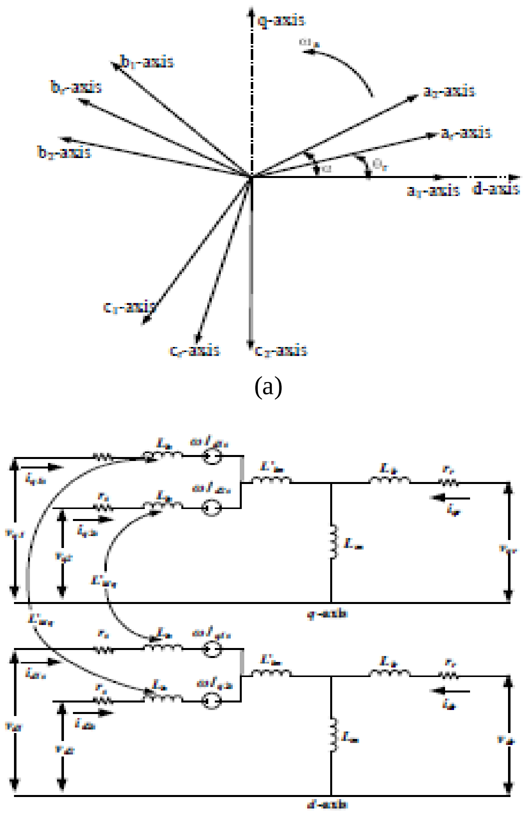
The interest has increased over the last two years due to international power electronic conferences held sessions on multi-phase inductive engine drives. Multi-phase motor drives have been researched over recent years. Major advantages of using multi-phase machines instead of three-phase machines are, (1) higher torque density. (2) Greater efficiency. (3) Reduced torque pulsation. (4) Greater fault intolerance. (5) Reduction in the required rating per inverter leg .

However, when a multi-phase system is implemented with a voltage source inverter with conventional six-step operation or space vector PWM control, surprisingly large harmonic currents have been observed**.** Although this peculiarity has drawn attention from people working on this kind of system, little work has been done in developing a dedicated control strategy to effectively suppress the harmonics due to the complexity of the converter-machine model. It is well known that the *d-q-0* reference frame transformation has long been used successfully in the analysis and control of three-phase electric machines. In this technology, the original three-dimensional vector space is decomposed into the direct sum of a *d-q* subspace and a zero sequence subspace, which is orthogonal to the d-q. By virtue of this decomposition, the components which produce rotating MMF and the components of zero sequence are total decoupled, and thus the analysis what's more, the control of the machine are improved .

Unwavering quality is one of the focal points in utilizing six-stage frameworks. On account of disappointment of one of the stages, either in the machine or in the power converter, the framework can at present work at a lower power rating since every three-stage gathering can be made autonomous from one another. On account of losing one stage, the six-stage machine can keep on being worked as a five-stage machine [10].

By using space vector decomposition and feed forward control we reduce the disturbance in the six phase induction motor. In the conventional method Pi controller based rotor field oriented controller improves the motor speed and gives the accurate results utilizing with feed forward current controller and without feed forward current controller.

In the proposed method fuzzy logic controller replaced by PI controller. It gives the comparison between with and without feed forward controller. In this paper break down the connection of six stage enlistment engine model, rotor field arranged controller, space vector beat width tweak and feed forward current controller.



(a)

(b)

Fig. 1: a) Phasor representation of an asymmetrical SPIM, b) d – q axis equivalent circuit of SPIM

II. Machine model:

Multiphase drive system consists of a VSC supplying SPIM. Multiphase induction machines can be modeled by either transforming individual pair of three-phase windings into 'n' number of phases [16] or by using vector space decomposition transformation [7]. In this paper, machine model is formulated in arbitrary frame of reference by transforming individual three-phases into two axes (d-q) machine model. Six-phase d -q model of induction machine is supplied from a six stage PWM converter acknowledged as far as exchanging capacities. An improved scientific demonstrating of six-stage acceptance engine and six-stage VSI are portrayed in this area.

a. Modeling of six phase induction machine:

Phasor representation of stator and rotor windings of asymmetrical SPIM is given in Fig. 1a. Two three-phase stator

Windings labeled $a1;\ b1;\ c1$ and $a2;\ b2;\ c2$ are displaced by thirty degrees. Neutral of both the winding sets are kept isolated to prevent physical fault transmission, and flow of triplen harmonic currents as mentioned earlier. Two stator windings of each three-phase are distributed uniformly and are displaced by 120°apart. The rotor windings $ar;\ br;\ cr$ are identical to the six-stage stator windings. The d-q tomahawks comparable circuit of the six-stage acceptance Machine is appeared in Fig. 1b. Voltage equations of SPIM in arbitrary frame of reference can be written as [16],

$$v_q^1 = r_1 i_q^1 + \omega_a \lambda_d^1 + p\,\lambda_q^1$$
$$v_d^1 = r_1 i_d^1 + \omega_a \lambda_q^1 + p\,\lambda_d^1$$
$$v_q^2 = r_2 i_q^2 + \omega_a \lambda_d^2 + p\,\lambda_q^2$$
$$v_d^2 = r_1 i_d^2 + \omega_a \lambda_q^2 + p\,\lambda_d^2$$
$$0 = r_r i_{qr} + (\omega_a - \omega_r)\lambda_d^r + p\,\lambda_q^r$$
$$0 = r_r i_{dr} + (\omega_a - \omega_r)\lambda_q^r + p\,\lambda_d^r$$

Where! A is the self-assertive reference speed and p indicates separation. Stator and rotor motion linkages can be communicated as,

$$\lambda_{q1} = L_{l1} i_{q1} + L_{lm}\, i_q - L_{ldq} i_{d2} + L_m(i_{q1} + i_{q2} + i_{qr})$$
$$\lambda_{d1} = L_{l1} i_{d1} + L_{lm}\, i_d - L_{ldq} i_{q2} + L_m(i_{d1} + i_{d2} + i_{dr})$$
$$\lambda_{q1} = L_{l2} i_{q2} + L_{lm}\, i_q - L_{ldq} i_{d1} + L_m(i_{q1} + i_{q2} + i_{qr})$$
$$\lambda_{d1} = L_{l2} i_{d1} + L_{lm}\, i_d - L_{ldq} i_{q2} + L_m(i_{d1} + i_{d2} + i_{dr})$$
$$\lambda_{qr} = L_{lr}\, i_{qr} + L_m(i_q + i_{qr})$$
$$\lambda_{dr} = L_{lr}\, i_{dr} + L_m(i_d + i_{dr})$$
$$L_{lm} = \frac{N_1}{N_2} L_{lm}, \qquad L_{ldq} = \frac{N_1}{N_2} L_{ldq}$$
$$i_q = i_{q1} + i_{q2}\ , \qquad i_d = i_{d1} + i_{d2}$$

Where L0 lm is the common mutual leakage inductance and L0 ldq is mutual leakage coupling between two stator windings. The torque equation of the induction machine can be expressed as

$$T_{em} = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left[(i_{q1} + i_{q2})i_{dr} - (i_{d1} + i_{d2})i_{qr}\right] \quad -----(1)$$

b. Six-phase voltage source converter

$$v_{a1} = \left(\frac{1}{3}\right)(2v_{A1} - v_{B1} - v_{C1})$$
$$v_{b1} = \left(\frac{1}{3}\right)(2v_{B1} - v_{C1} - v_{A1})$$
$$v_{C1} = \left(\frac{1}{3}\right)(2v_{C1} - v_{A1} - v_{B1})$$
$$v_{a2} = \left(\frac{1}{3}\right)(2v_{A2} - v_{B2} - v_{C2})$$
$$v_{b2} = \left(\frac{1}{3}\right)(2v_{B2} - v_{C2} - v_{A2})$$
$$v_{C2} = \left(\frac{1}{3}\right)(2v_{C2} - v_{A2} - v_{B2})$$
$$v_{d1q1} = v_{d1} + jv_{q1} = 0.33(v_{a1} + a^4 v_{b1} + a^8 v_{c1} + a v_{a2} + a^5 v_{b2} + a^9 v_{c2}) \quad -----(2)$$
$$v_{d2q2} = v_{d2} + jv_{q2} = 0.33(v_{a1} + a^4 v_{b1} + a^8 v_{c1} + a v_{a2} + a^5 v_{b2} + a^9 v_{c2}) \quad -----(3)$$

Where, $a = exp\,(\frac{j\pi}{6})$

An m-level n-phase inverter has mn space vectors; therefore, a six-phase two-level VSI has 26 i.e. 64 space vectors, corresponding to the 64 switching states. They are comprised of 48 active vectors, 4 null vectors and 12 superimposed redundant vectors. Increased number of switching vectors allows smooth transmission of output voltage between the adjacent voltage vectors. The output phases of SPIM are denoted as a1,b1,c1 and a2,b2,c2 and inverter leg pole points as A1,A2,B1,B2,C1,C2. Phase voltages can be realized in terms of inverter leg voltages as,

In a six-phase VSI, voltages are projected into a six dimensional space having two orthogonal two dimensional planes called as d1-q1 and d2-q2 and a zero sequence plane 01- 02. Space vectors for SPIM in stationary frame, using power invariant transformation can be defined as, Space vectors in d1-q1 plane of a six-phase VSI are shown in the Fig. 3. Depending on the magnitude, active vectors are classified as largest, second largest, third largest and shortest vectors. 12 redundant vectors resides along with third largest vectors, therefore they can be synthesized by either of the two switching state combinations. Null vectors are mapped to the origin.

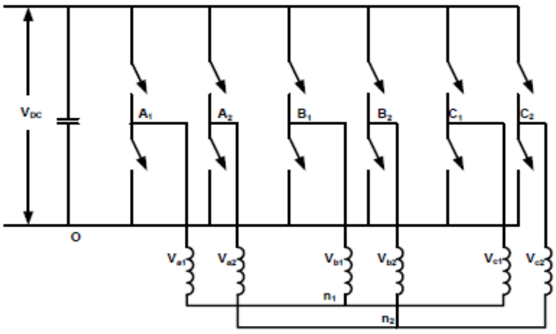


Fig. 2. Six – phase voltage source inverter connected to SPIM

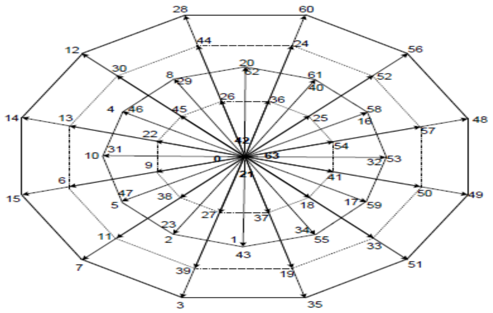


Fig. 3. Six phase VSI phase voltage space vectors in d – q plane

III. Field oriented control strategy:

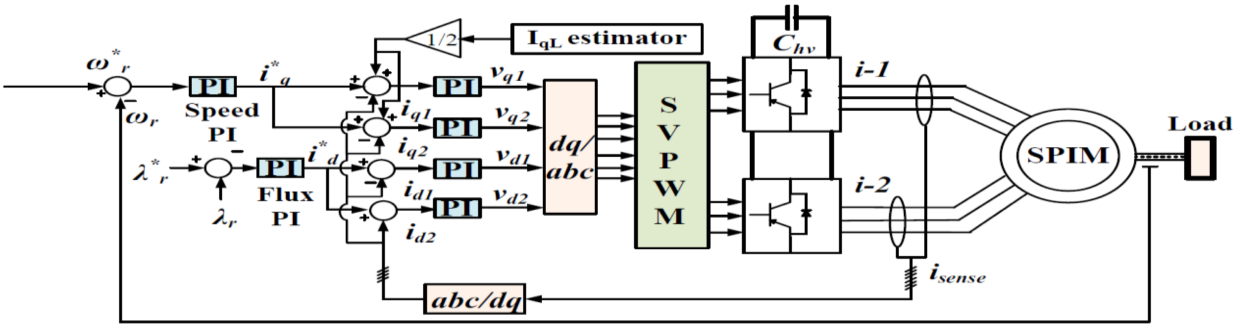


Fig. 4. Rotor field oriented control

Speed control system of SPIM is appeared in Fig. 4. In this work, rotor field arranged control (RFOC) with two sets of d-q current controllers is implemented for SPIM speed control. RFOC independently controls the machine torque and flux. In order to do so, d- and q -axis variables must be decoupled from each other. Dynamic voltage equations in terms of flux linkage and stator currents can be written as,

$$V_{ds1} = R_s\left[1+\frac{T_s(1-\sigma)}{T_r}\right]i_{ds1}+\sigma L_s\frac{d_i d_{s1}}{dt}-\omega_a\sigma L_s i_{qs1}-\omega_a(\sigma L_s-L_{ls})i_{qs2}+\frac{L_s(1-\sigma)}{T_r}i_{ds2}-\frac{L_m}{L_rT_r}\lambda_r + (\sigma L_s-L_{ls})\frac{d}{dt}\,i_{ds2}\ ---(4)$$

$$V_{qs1} = R_s\left[1+\frac{T_s(1-\sigma)}{T_r}\right]i_{qs1}+\sigma L_s\frac{d_{iqs1}}{dt}+\omega_a\sigma L_s i_{ds1}+\omega_a(\sigma L_s-L_{ls})i_{ds2}+\omega_a\frac{L_m}{L_r}\lambda_r+\frac{L_s(1-\sigma)}{T_r}i_{qs2} + (\sigma L_s-L_{ls})\frac{d}{dt}\,i_{qs2}\ ---(5)$$

$$V_{ds2} = R_s\left[1+\frac{T_s(1-\sigma)}{T_r}\right]i_{ds2}+\sigma L_s\frac{d_i d_{s2}}{dt}-\omega_a\sigma L_s i_{qs2}-\omega_a(\sigma L_s-L_{ls})i_{qs1}+\frac{L_s(1-\sigma)}{T_r}i_{ds1}-\frac{L_m}{L_rT_r}\lambda_r + (\sigma L_s-L_{ls})\frac{d}{dt}\,i_{ds1}\ ---(6)$$

$$V_{qs2} = R_s\left[1+\frac{T_s(1-\sigma)}{T_r}\right]i_{qs2}+\sigma L_s\frac{d_i q_{s2}}{dt}+\omega_a\sigma L_s i_{ds2}+\omega_a(\sigma L_s-L_{ls})i_{ds1}+\omega_a\frac{L_m}{L_r}\lambda_r+\frac{L_s(1-\sigma)}{T_r}i_{qs1} + (\sigma L_s-L_{ls})\frac{d}{dt}\,i_{qs1}\ ---(7)$$

Where,

$$\sigma = 1-\frac{L_m^2}{L_sL_r},Ts=\frac{L_s}{R_s},Tr=\frac{L_r}{R_r}$$

The d-axis transition linkages are thought to be lined up with the rotor motion linkage vector _r and q-hub motion linkages are set to zero. As d-hub current is responsible for the transition generation, it is renamed as if and q-center point current is accountable for torque production it is renamed as . The rotor flux-linkages are given by, the rotor currents can be rewritten with respect to (8) as, the electromagnetic torque can be given by,

$$\lambda_r = \lambda_d r, \lambda_{qr} = 0 ------(8)$$

The rotor flows can be modified regarding (8) as,

$$i_f = \left(\frac{1}{Lm}\right)[1+Tr\rho]\lambda_r ---(9)$$

$$\omega_{sl} = \left(\frac{Lm}{Tr}\right)\left[\frac{i_T}{\lambda_r}\right] ----(10)$$

Where,

$$i_f = i_{d1}+i_{d2}, \qquad i_T = i_{q1}+i_{q2} \qquad T_r = \frac{L_r}{r_r}$$

The electromagnetic torque can be given by,

$$T_e = K_e\,\lambda_r\,i_T ----(11)$$

Where,

$$K_e = \left(\frac{3}{2}\right)\left(\frac{p}{2}\right)\left(\frac{L_m}{L_r}\right) --- (12)$$

The implementation methodology of rotor field oriented control involves six PI controllers. PI values are obtained by designing transfer function of the SPIM with RFOC. The outer PI controller is used for speed control and flux control, which generate reference currents i_q and$i_ d$. Internally; four PI controllers are used to control the direct and quadrature currents of two sets of windings in SPIM. These PI controllers generate the reference voltage for PWM converters

A. Disturbance reduction feed-forward loop

The main objective of any control technique is to improve the system speed response, but a change in load torque will cause a sluggish reaction and affect the speed under closed loop control. In order to avoid this kind of interference, a modification in the existing RFOC is proposed by feed forwarding load torque compensating currentiqL. However, load torque measurement is very difficult in real time, therefore a method to estimate the load torque from rotor speed, and electromechanical torque is discussed in this section. Using speed dynamic equations, load torque can be written as,

$$T_l = T_e - BT\omega_r - J\frac{d\omega_r}{dt} ----(13)$$

With a discrete time distinction, previously mentioned condition can be composed as,

$$T_l(k) = T_e(k-1) - B\omega_r(k-1) - J\frac{(\omega_r(k)-\omega_r(k-1))}{t_s} -- - (14)$$

By substituting for Te from conditions (11) and (12), load torque can be modified as,

$$T_l(k) = k_e\lambda_r(k-1) - B\omega_r(k-1) - J\frac{(\omega_r(k)-\omega_r(k-1))}{t_s} -- - (15)$$

Load torque compensating current iql can be obtained by following equation

$$i_{qL} = \frac{2Lr}{pLm\lambda_r} Tl(k) = G1Tl(k) --- (16)$$

Effective sum of iqs and iqL are capable of compensating for the change in load torque, and simultaneously maintain the desired speed demand. Estimation of load torque compensating current iqL is shown in Fig. 5. Feed forwarding input load torque as an equivalent q-axis current in current loop gives effective improvement in speed response.

B. Space vector decomposition model

SVPWM techniques can improve the current quality in a multiphase machine [17]. Vector space decomposition proposed by Zhao and Lipo in [7] is most utilized SVPWM technique. In this method, along with one null vector four active space vectors of the largest magnitude adjacent to the reference vector are considered to synthesize space vector.

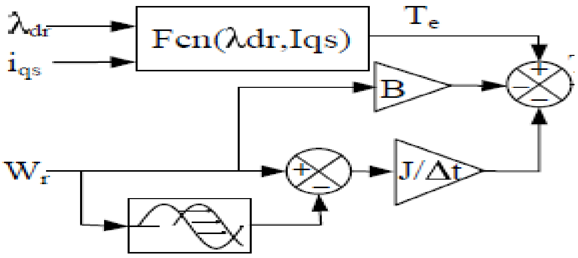


Fig. 5. Feed forwarding load torque as an equivalent q − axis current iql.

Vector switching times can be calculated by volt-second balance from the following equation

$$T_1 v_d^1 + T_2 v_d^2 + T_3 v_d^3 + T_4 v_d^4 + T_0 v_d^5 = T_s v_d^* --(17)$$

$$T_1 v_q^1 + T_2 v_q^2 + T_3 v_q^3 + T_4 v_q^4 + T_0 v_q^5 = T_s v_q^* --(18)$$

$$T_1 v_x^1 + T_2 v_x^2 + T_3 v_x^3 + T_4 v_x^4 + T_0 v_x^5 = 0 --(19)$$

$$T_1 v_y^1 + T_2 v_y^2 + T_3 v_y^3 + T_4 v_y^4 + T_0 v_y^5 = 0 --(20)$$

$$T_1 + T_2 + T_3 + T_4 + T_0 = T_s --(21)$$

Where, $d - q$ and $x - y$ subscripts denotes the In the real plane, elements of space vectors. v1 to v4 Shows four neighbouring space active vectors and v5 is space null. T0 to T4 are the corresponding vector switching times. This PWM technique offers the optimum output d-q voltage by reducing the harmonics of the X-y plane.

IV. controller designing using Fuzzy logic controller

Fuzzy rule is a type of multi-familiar justification in which factual estimates of factors may be a true variety of some zero and 1 areas. Special estimates of realities of additives may definitely also be 0 or 1 in the Boolean method of reasoning.

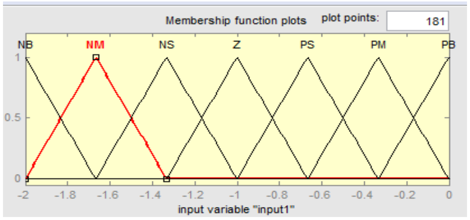


Fig. 6. input − 1 membership function

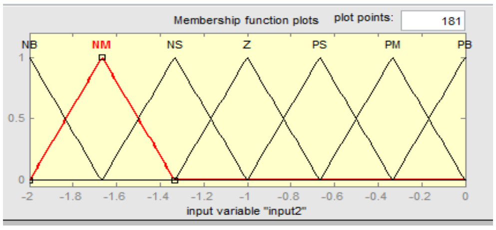


Fig. 7. Input − 2 membership function

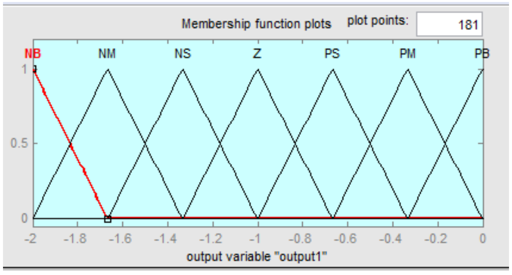


Fig. 8. output membership function

Fuzzy method monitor the potential for partial truth has been contacted, where truth can go between obvious and totally false. In addition, these levels are likely to be controlled using particular capability when semantic variables are being used.

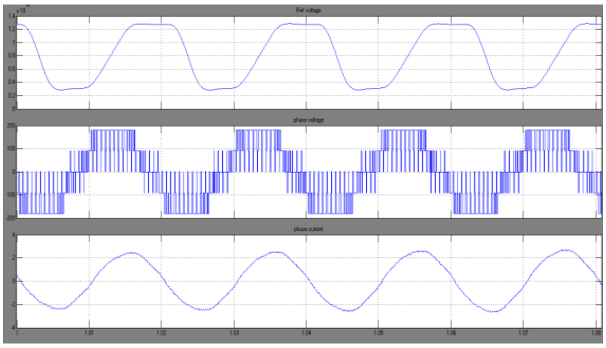
There are seven triangles in the FLC's three variables, the mistake, the error trading and the production. As shown in Figures 6,7,8, the fundamental fluid units of the member feature of the variables are. Semane factor Negative big (NB), Negative large (NM), Negative small (NS), Positive small(PS) and Positive big(PB) for each of these three factors is reported as fuzzy factors. A lead in the governing base can be stated in the form: If (e is NB) and (de is NB) (album is NB). The concepts are laid down in view of the system knowledge and the framework functioning. The administration of the base alters the inverter obligation period in compliance with the FLC contribution adjustments. The number of principles can be calculated as desired. For the five elements of inscription, the amounts of the guidelines sum to 49 (contributions of the FLC).

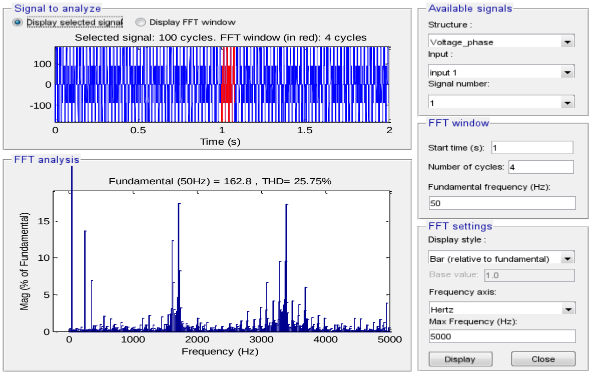
E /CE	***NB***	***NM***	***NS***	***ZE***	***PS***	***PM***	***PB***
NB	***NB***	***NB`***	***NB***	***NB***	***NM***	***NS***	***ZE***
NM	***NB***	***NB***	***NB***	***NM***	***NS***	***ZE***	***PS***
NS	***NB***	***NB***	***NM***	***NS***	***ZE***	***PS***	***PM***
ZE	***NB***	***NM***	***NS***	***ZE***	***PS***	***PM***	***PB***
PS	***NM***	***NS***	***ZE***	***PS***	***PM***	***PB***	***PB***
PM	***NS***	***ZE***	***PS***	***PM***	***PB***	***PB***	***PB***
PB	***ZE***	***PS***	***PM***	***PB***	***PB***	***PB***	***PB***

Table.1. fuzzy logic rules

V. Simulation results

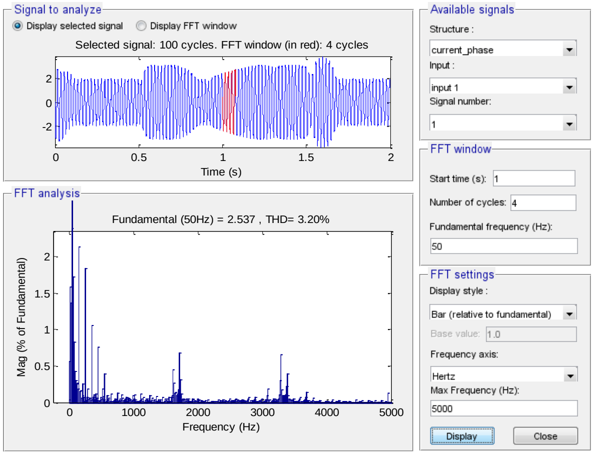
1. Performance of field oriented control using PI control




Signal to analyze
● Display selected signal ○ Display FFT window
Selected signal: 100 cycles. FFT window (in red): 4 cycles

FFT analysis
Fundamental (50Hz) = 162.8 , THD= 25.75%

Available signals
Structure : Voltage_phase
Input : input 1
Signal number: 1
FFT window
Start time (s): 1
Number of cycles: 4
Fundamental frequency (Hz): 50
FFT settings
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 5000


Signal to analyze
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Selected signal: 100 cycles. FFT window (in red): 4 cycles

FFT analysis
Fundamental (50Hz) = 2.537 , THD= 3.20%

Available signals
Structure : current_phase
Input : input 1
Signal number: 1
FFT window
Start time (s): 1
Number of cycles: 4
Fundamental frequency (Hz): 50
FFT settings
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 5000

Fig. 9. Vector space decomposition SVPWM waveform. From top to bottom: Reference signal, phase voltage with frequency spectra, phase current with frequency spectra

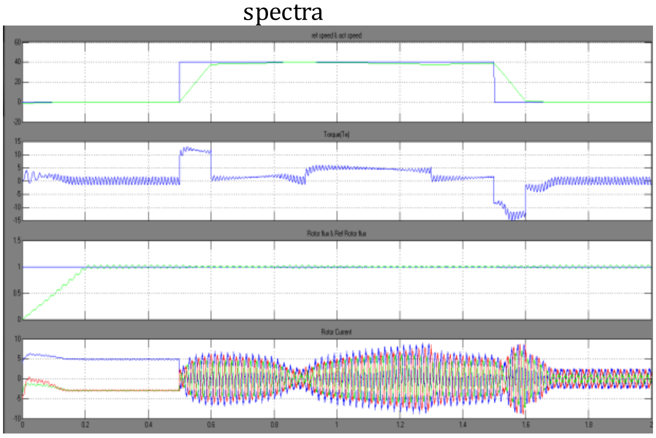


Fig. 10. Simulated waveforms of; speed, torque, rotor flux, and motor currents

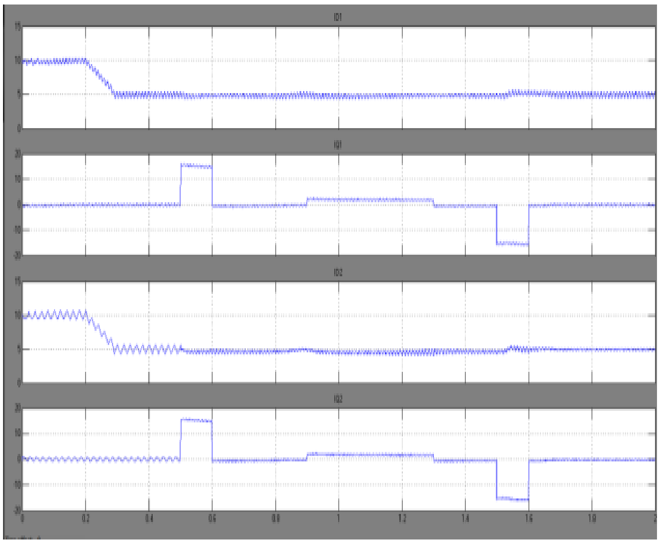


Fig. 11. Simulated waveforms of q − axis and d − axis currents in the synchronous frame of reference.

2. Performance of field oriented control using FUZZY control

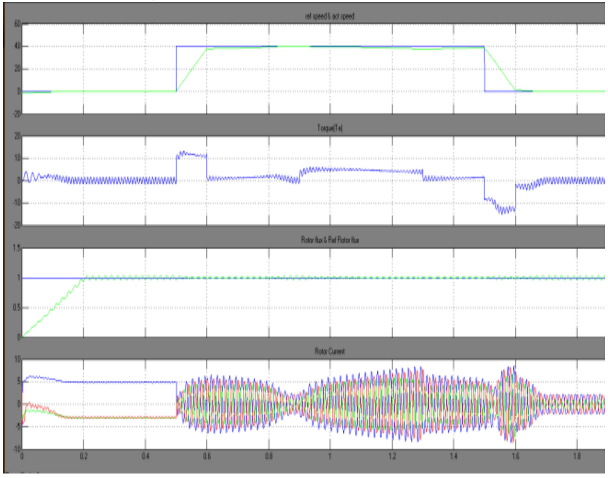
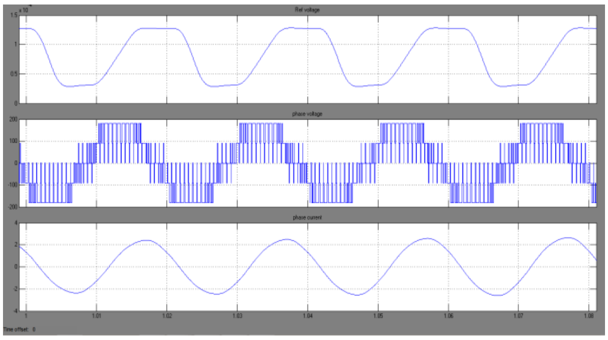
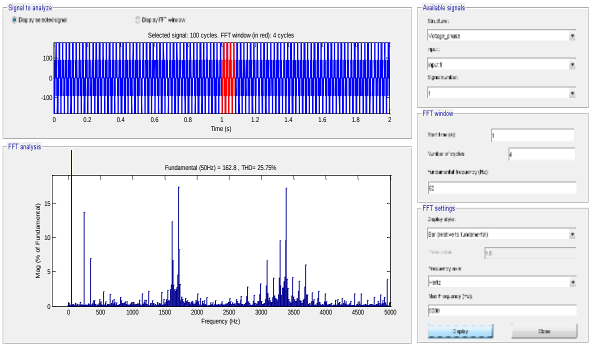


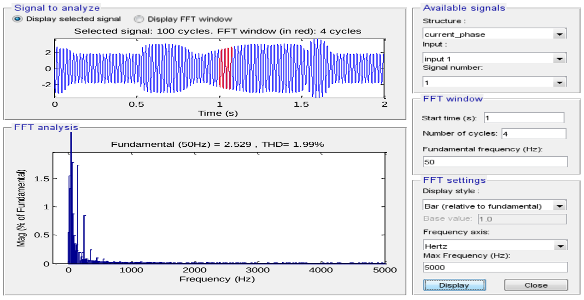
Fig. 12. Simulated waveforms of; speed, torque, rotor flux, and motor currents





Selected signal: 100 cycles. FFT window (in red): 4 cycles

Fundamental (50Hz) = 162.8 , THD= 25.75%



● Display selected signal ○ Display FFT window

Selected signal: 100 cycles. FFT window (in red): 4 cycles

Fundamental (50Hz) = 2.529 , THD= 1.99%

Structure : current_phase

Input : input 1

Signal number: 1

Start time (s): 1

Number of cycles: 4

Fundamental frequency (Hz): 50

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 5000

Fig. 13. Vector space decomposition SVPWM waveform. From top to bottom: Reference signal, phase voltage with frequency spectra, phase current with frequency spectra

VI. Conclusion:

The relation can be studied using rotor field control arranged and feed forward strategies discussed in this paper in this project six phases induction motor control. Due to the increased speed of the induction motor, controllers can be reduced. The relationship of PI controller, fugitive logic controller, is broken in this article. The results were obtained with and ohne controller in this paper feed forwarding loop. The checker relation was evaluated in THD value.

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